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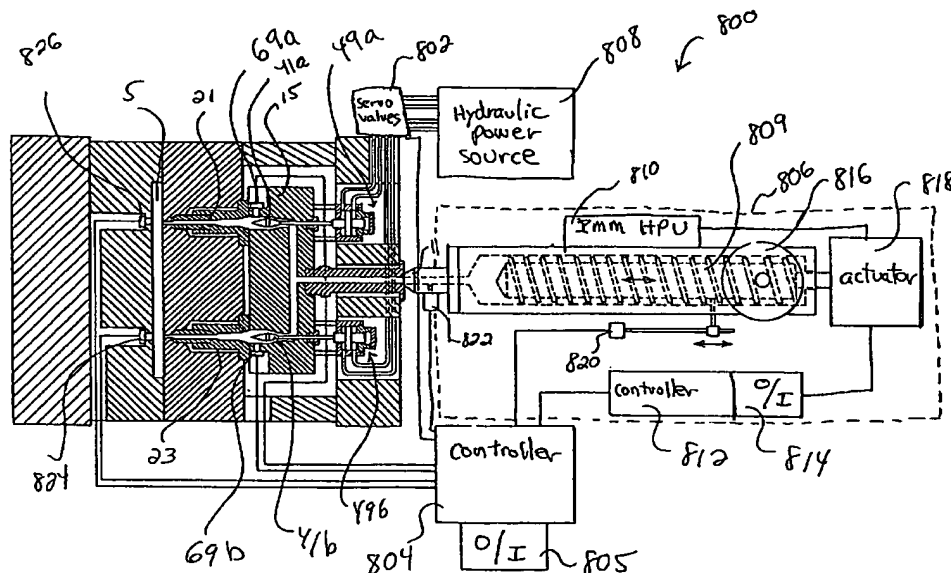
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(54) Title: DYNAMIC FEED CONTROL SYSTEM



(57) Abstract: An injection molding apparatus and system are provided in which the rate of material flow during the injection cycle is controlled. According to one preferred embodiment, an injection molding system is provided that includes an injection molding machine including a hydraulic power source, a manifold for distributing material injected from said injection molding machine to a plurality of gates leading to one or more mold cavities, and a controller to individually control respective rates at which material is injected through said gates during an injection cycle. The controller is coupled to the hydraulic power source and the hydraulic power source supplies hydraulic power to both the injection molding machine and to control said respective rates.

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**DYNAMIC FEED CONTROL SYSTEM****Related Applications**

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This application is a Continuation-in-Part under 35 U.S.C. §120 of U.S. Application Serial No. 09/400,533, entitled "MANIFOLD SYSTEM HAVING FLOW CONTROL", filed September 21, 1999, which is a Continuation-in-Part of U.S. Application Serial No. 09/063,762, entitled "MANIFOLD SYSTEM HAVING FLOW CONTROL" filed April 21, 1998, and claims priority under 35 U.S.C. §119(e) to Provisional Application Serial No. 60/156,925, entitled "DYNAMIC FEED CONTROL" filed September 28, 1999.

**Field of the Invention**

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This invention relates to injection of pressurized materials through a manifold, such as injection molding of plastic melt in a hot runner system. More specifically, this invention relates to an improved injection molding hot runner system in which the rate of melt flow is controlled through the gate during an injection molding cycle.

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**Description of the Related Art**

United States Patent No. 5,556,582 discloses a multi-gate single cavity system in which the rate of melt flow through the individual gates is controlled independently via a control system according to specific target process conditions. This system enables the weld line of the part (the section of the part in which the melt from one gate meets the melt from another gate) to be selectively located. It also enables the shape of the weld line to be altered to form a stronger bond.

The '582 patent discloses controlling the rate of melt flow with a tapered valve pin at the gate to the mold cavity. It also discloses placing a pressure transducer inside the mold cavity. Placing the pressure transducer inside the mold cavity can result in the pressure transducer sensing pressure spikes which can occur when the valve pin is closed. A pressure spike sensed by the transducer can cause an unintended response from the control system, and result in a less precise control of the melt flow than desired.

The control system disclosed in the '582 patent uses the variables of valve pin position and cavity pressure to determine what position the valve pin should be in. Thus,

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the algorithm performed by the control system in the '582 patent utilizes two variables to control the rate of melt flow into the cavity.

### **Summary of the Invention**

5           An injection molding apparatus and system are provided in which the rate of material flow during the injection cycle is controlled. According to one preferred embodiment, an injection molding system is provided that includes an injection molding machine including a hydraulic power source, a manifold for distributing material injected from said injection molding machine to a plurality of gates leading to one or more mold  
10   cavities, and a controller to individually control respective rates at which material is injected through said gates during an injection cycle. The controller is coupled to the hydraulic power source and the hydraulic power source supplies hydraulic power to both the injection molding machine and to control said respective rates.

          According to another embodiment, an injection molding system is provided that  
15   includes an injection molding machine, and a manifold for distributing material injected from said injection molding machine to a plurality of gates leading to one or more mold cavities. The injection molding machine includes a controller to individually control respective rates at which material is injected through said gates during an injection cycle.

          According to another embodiment, an injection molding system is provided that  
20   includes an injection molding machine, a manifold for distributing material injected from a nozzles of said injection molding machine to a plurality of gates leading to one or more mold cavities, a controller to individually control respective rates at which material is injected through said gates during an injection cycle, and a pressure transducer coupled to the nozzle of said injection molding machine. The controller receives pressure data  
25   from the pressure transducer.

          According to another embodiment, an injection molding system is provided that includes an injection molding machine, a manifold for distributing material injected from a plurality of nozzles of said injection molding machine to a plurality of gates leading to one or more mold cavities, a controller to individually control respective rates at which  
30   material is injected through said gates during an injection cycle, and a position transducer coupled to a screw of said injection molding machine. The controller receives position data of the screw from the position transducer.

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According to another embodiment, an injection molding system is provided that includes an injection molding machine, a hot runner including a manifold and a plurality of injection nozzles for distributing material injected from said injection molding machine to a plurality of gates leading to one or more mold cavities, a controller to  
5 individually control respective rates at which material is injected through said gates during an injection cycle, and at least one pressure transducer mounted in the one or more cavities, the pressure transducer coupled to the controller to send pressure data to the controller. The controller alters the at least one respective rate from an injection pressure to a pack pressure when the pressure transducer detects a predetermined  
10 pressure value.

According to another embodiment, an injection molding system is provided that includes an injection molding machine, a hot runner including a manifold and a plurality of injection nozzles for distributing material injected from said injection molding machine to a plurality of gates leading to one or more mold cavities, a controller to  
15 individually control respective rates at which material is injected through said gates during an injection cycle, and at least one pressure transducer mounted in the one or more cavities, the pressure transducer coupled to the controller to send pressure data to the controller. The controller determines an end of the pack period of the injection cycle for at least one respective rate when the pressure transducer detects a predetermined  
20 pressure value.

According to another embodiment, an injection molding system is provided that includes an injection molding machine, a hot runner including a manifold and a plurality of injection nozzles for distributing material injected from said injection molding machine to a plurality of gates leading to one or more mold cavities, a plurality of  
25 pressure transducers coupled to said hot runner for sensing material pressure flowing to said gates, and at least one pressure transducer mounted in the one or more cavities, the pressure transducer to sense the material pressure inside the one or more cavities.

#### **Brief Description of the Drawings**

30 Figure 1 is a partially schematic cross-sectional view of an injection molding system according to one embodiment of the present invention;

Figure 2 is an enlarged fragmentary cross-sectional view of one side of the injection molding system of Figure 1;

Figure 3 is an enlarged fragmentary cross-sectional view of an alternative embodiment of a system similar to Figure 1, in which a plug is used for easy removal of  
5 the valve pin;

Figure 4 is an enlarged fragmentary cross-sectional view of an alternative embodiment of a system similar to Figure 1, in which a threaded nozzle is used;

Figure 5 is a view similar to Figure 4, showing an alternative embodiment in which a plug is used for easy removal of the valve pin;

10 Figure 6 shows a fragmentary cross-sectional view of a system similar to Figure 1, showing an alternative embodiment in which a forward shut-off is used;

Figure 7 shows an enlarged fragmentary view of the embodiment of Figure 6, showing the valve pin in the open and closed positions, respectively;

Figure 8 is a cross-sectional view of an alternative embodiment of the present  
15 invention similar to Figure 6, in which a threaded nozzle is used with a plug for easy removal of the valve pin;

Figure 9 is an enlarged fragmentary view of the embodiment of Figure 8, in which the valve pin is shown in the open and closed positions;

Figure 10 is an enlarged view of an alternative embodiment of the valve pin,  
20 shown in the closed position;

Figure 11 is a fragmentary cross sectional view of an alternative embodiment of an injection molding system having flow control that includes a valve pin that extends to the gate;

Figure 12 is an enlarged fragmentary cross-sectional detail of the flow control  
25 area;

Figure 13 is a fragmentary cross sectional view of another alternative embodiment of an injection molding system having flow control that includes a valve pin that extends to the gate, showing the valve pin in the starting position prior to the beginning of an injection cycle;

30 Figure 14 is view of the injection molding system of Figure 13, showing the valve pin in an intermediate position in which material flow is permitted;

Figure 15 is a view of the injection molding system of Figure 13, showing the valve pin in the closed position at the end of an injection cycle; and

Figure 16 shows a series of graphs representing the actual pressure versus the target pressure measured in four injection nozzles coupled to a manifold as shown in  
5 Figure 13;

Figures 17 and 18 are screen icons displayed on interface 114 of Figure 13 which are used to display, create, edit, and store target profiles;

Figure 19 is a fragmentary cross-sectional partially schematic view of another alternative embodiment of an injection molding system having flow control in which a  
10 ram is used to inject material from a well in the manifold into the mold cavity;

Figure 20 is a fragmentary view of the embodiment shown in Figure 19 in which the well 640 is being filled by the injecting molding machine;

Figure 21 is a view similar to Figure 20 in which the well is full of material and the system is ready to inject material into the mold cavity;

15 Figure 22 is a view similar to Figures 20 and 21 in which injection into the mold cavity has begun;

Figure 23 is a view similar to Figures 20-22 in which the injection cycle is complete;

Figure 24 is a cross-sectional partially schematic view of another alternative  
20 embodiment of an injection molding system having flow control in which a load cell behind the valve pin is used to control the flow rate in each injection nozzle;

Figure 25 is an enlarged fragmentary cross-sectional view of the valve pin and actuator of Figure 24;

Figure 26 is an enlarged view of the load cell and valve pin of Figure 24;

25 Figures 27A and 27B show an enlarged view of the tip of the valve pin closing the gate and controlling the flow rate, respectively;

Figures 28A and 28B shown an alternative structure of an injection molding nozzle for use in the system shown in Figure 24;

Figure 29 is a cross-sectional partially schematic view of an alternative  
30 embodiment of an injection molding system having flow control similar to Figure 19 in which a pressure transducer is used to sense the hydraulic pressure supplied to the actuator;

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Figure 30 shows a fragmentary cross-sectional view of an alternative embodiment of an injection molding system having flow control similar to Figure 13 in which the pressure transducer is mounted in the mold cavity; and

Figure 31 is a fragmentary cross-sectional view of an alternative embodiment of an injection molding system having flow control in which flow control is achieved by measuring the differential pressure of the actuator chambers.

Figure 32 is a schematic representation of an injection molding system utilizing the hot runner system shown in Figure 1;

Figure 33 is an alternative embodiment of the system of Figure 32 in which the hydraulic power source associated with the servo valves 802 has been integrated with the injection molding machine hydraulic power unit;

Figure 34 is an alternative embodiment of the injection molding systems shown in Figures 32 and 33 in which the controller 804 and operator interface 805 have been integrated in the injection molding machine controller 830 and interface 832; and

Figure 35 is an alternative embodiment of the injection molding system of Figure 32 in which the cavity pressure transducers 824 and 826 are located at the end of two mold cavities 5a and 5b.

### **Detailed Description**

Figures 1-2 show one embodiment of the injection molding system according to the present invention. The injection molding system 1 is a multi-gate single cavity system in which melt material 3 is injected into a cavity 5 from gates 7 and 9. Melt material 3 is injected from an injection molding machine 11 through an extended inlet 13 and into a manifold 15. Manifold 15 distributes the melt through channels 17 and 19. Although a hot runner system is shown in which plastic melt is injected, the invention is applicable to other types of injection systems in which it is useful to control the rate at which a material (e.g., metallic or composite materials) is delivered to a cavity.

Melt is distributed by the manifold through channels 17 and 19 and into bores 18 and 20 of nozzles 21 and 23, respectively. Melt is injected out of nozzles 21 and 23 and into cavity 5 (where the part is formed) which is formed by mold plates 25 and 27. Although a multi-gate single-cavity system is shown, the invention is not limited to this type of system, and is also applicable to, for example, multi-cavity systems, as discussed in greater detail below.



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The injection nozzles 21 and 23 are received in respective wells 28 and 29 formed in the mold plate 27. The nozzles 21 and 23 are each seated in support rings 31 and 33. The support rings serve to align the nozzles with the gates 7 and 9 and insulate the nozzles from the mold. The manifold 15 sits atop the rear end of the nozzles and  
5 maintains sealing contact with the nozzles via compression forces exerted on the assembly by clamps (not shown) of the injection molding machine. An O-ring 36 is provided to prevent melt leakage between the nozzles and the manifold. A dowel 73 centers the manifold on the mold plate 27. Dowels 32 and 34 prevent the nozzle 23 and support ring 33, respectively, from rotating with respect to the mold 27.

10 The nozzles also include a heater 35 (Figure 2). Although an electric band heater is shown, other heaters may be used. Furthermore, heat pipes (for example those disclosed in U.S. Patent No. 4,389,002) may be disposed in each nozzle and used alone or in conjunction with heater 35. The heater is used to maintain the melt material at its processing temperature up to the gates 7 and 9. The nozzles 21 and 23 also include an  
15 insert 37 and a tip 39. The insert can be made of a material (for example beryllium copper) having high thermal conductivity in order to maintain the melt at its processing temperature up to the gate by imparting heat to the melt from the heater 35. The tip 39 is used to form a seal with the mold plate 27 and is preferably a material (for example titanium alloy or stainless steel) having low thermal conductivity so as to reduce heat  
20 transfer from the nozzle to the mold.

A valve pin 41 having a head 43 is used to control the rate of flow of the melt material to the respective gates 7 and 9. The valve pin reciprocates through the manifold. A valve pin bushing 44 is provided to prevent melt from leaking along stem 102 of the valve pin. The valve pin bushing is held in place by a threadably  
25 mounted cap 46. The valve pin is opened at the beginning of the injection cycle and closed at the end of the cycle. During the cycle, the valve pin can assume intermediate positions between the fully open and closed positions, in order to decrease or increase the rate of flow of the melt. The head includes a tapered portion 45 that forms a gap 81 with a surface 47 of the bore 19 of the manifold. Increasing or decreasing the size of the gap  
30 by displacing the valve pin correspondingly increases or decreases the flow of melt material to the gate. When the valve pin is closed the tapered portion 45 of the valve pin head contacts and seals with the surface 47 of the bore of the manifold.

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Figure 2 shows the head of the valve pin in a Phantom dashed line in the closed position and a solid line in the fully opened position in which the melt is permitted to flow at a maximum rate. To reduce the flow of melt, the pin is retracted away from the gate by an actuator 49, to thereby decrease the width of the gap 81 between the valve pin and the bore 19 of the manifold.

The actuator 49 (for example, the type disclosed in application serial no. 08/874,962) is mounted in a clamp plate 51 which covers the injection molding system 1. The actuator 49 is a hydraulic actuator, however, pneumatic or electronic actuators can be used. The actuator 49 includes a hydraulic circuit that includes a movable piston 53 in which the valve pin 41 is threadably mounted at 55. Thus, as the piston 53 moves, the valve pin 41 moves with it. The actuator 49 includes hydraulic lines 57 and 59 which are controlled by servo valves 1 and 2. Hydraulic line 57 is energized to move the valve pin 41 toward the gate to the open position, and hydraulic line 59 is energized to retract the valve pin away from the gate toward the close position. An actuator cap 61 limits longitudinal movement in the vertical direction of the piston 53. O-rings 63 provide respective seals to prevent hydraulic fluid from leaking out of the actuator. The actuator body 65 is mounted to the manifold via screws 67.

A pressure transducer 69 is used to sense the pressure in the manifold bore 19 downstream of the valve pin head 43. In operation, the conditions sensed by the pressure transducer 69 associated with each nozzle are fed back to a control system that includes controllers PID 1 and PID 2 and a CPU shown schematically in Figure 1. The CPU executes a PID (proportional, integral, derivative) algorithm which compares the sensed pressure (at a given time) from the pressure transducer to a programmed target pressure (for the given time). The CPU instructs the PID controller to adjust the valve pin using the actuator 49 in order to mirror the target pressure for that given time. In this way a programmed target pressure profile for an injection cycle for a particular part for each gate 7 and 9 can be followed.

Although in the disclosed embodiment the sensed condition is pressure, other sensed conditions can be used which relate to melt flow rate. For example, the position of the valve pin or the load on the valve pin could be the sensed condition. If so, a position sensor or load sensor, respectively, could be used to feed back the sensed condition to the PID controller. In the same manner as explained above, the CPU would

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use a PID algorithm to compare the sensed condition to a programmed target position profile or load profile for the particular gate to the mold cavity, and adjust the valve pin accordingly.

Melt flow rate is directly related to the pressure sensed in bore 19. Thus, using  
5 the controllers PID 1 and PID 2, the rate at which the melt flows into the gates 7 and 9 can be adjusted during a given injection molding cycle, according to the desired pressure profile. The pressure (and rate of melt flow) is decreased by retracting the valve pin and decreasing the width of the gap 81 between the valve pin and the manifold bore, while the pressure (and rate of melt flow) is increased by displacing the valve pin toward the  
10 gate 9, and increasing the width of the gap 81. The PID controllers adjust the position of the actuator piston 51 by sending instructions to servo valves 1 and 2.

By controlling the pressure in a single cavity system (as shown in Figure 1) it is possible to adjust the location and shape of the weld line formed when melt flow 75 from gate 7 meets melt flow 77 from gate 9 as disclosed in U.S. Patent No. 5,556,582.  
15 However, the invention also is useful in a multi-cavity system. In a multi-cavity system the invention can be used to balance fill rates and packing profiles in the respective cavities. This is useful, for example, when molding a plurality of like parts in different cavities. In such a system, to achieve a uniformity in the parts, the fill rates and packing profiles of the cavities should be as close to identical as possible. Using the same  
20 programmed pressure profile for each nozzle, unpredictable fill rate variations from cavity to cavity are overcome, and consistently uniform parts are produced from each cavity.

Another advantage of the present invention is seen in a multi-cavity system in which the nozzles are injecting into cavities which form different sized parts that require  
25 different fill rates and packing profiles. In this case, different pressure profiles can be programmed for each respective controller of each respective cavity. Still another advantage is when the size of the cavity is constantly changing, i.e., when making different size parts by changing a mold insert in which the part is formed. Rather than change the hardware (e.g., the nozzle) involved in order to change the fill rate and  
30 packing profile for the new part, a new program is chosen by the user corresponding to the new part to be formed.

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The embodiment of Figures 1 and 2 has the advantage of controlling the rate of melt flow away from the gate inside manifold 15 rather than at the gates 7 and 9. Controlling the melt flow away from the gate enables the pressure transducer to be located away from the gate (in Figures 1-5). In this way, the pressure transducer does not have to be placed inside the mold cavity, and is not susceptible to pressure spikes which can occur when the pressure transducer is located in the mold cavity or near the gate. Pressure spikes in the mold cavity result from the valve pin being closed at the gate. This pressure spike could cause an unintended response from the control system, for example, an opening of the valve pin to reduce the pressure — when the valve pin should be closed.

Avoidance of the effects of a pressure spike resulting from closing the gate to the mold makes the control system behave more accurately and predictably. Controlling flow away from the gate enables accurate control using only a single sensed condition (e.g., pressure) as a variable. The '582 patent disclosed the use of two sensed conditions (valve position and pressure) to compensate for an unintended response from the pressure spike. Sensing two conditions resulted in a more complex control algorithm (which used two variables) and more complicated hardware (pressure and position sensors).

Another advantage of controlling the melt flow away from the gate is the use of a larger valve pin head 43 than would be used if the valve pin closed at the gate. A larger valve pin head can be used because it is disposed in the manifold in which the melt flow bore 19 can be made larger to accommodate the larger valve pin head. It is generally undesirable to accommodate a large size valve pin head in the gate area within the end of the nozzle 23, tip 39 and insert 37. This is because the increased size of the nozzle, tip and insert in the gate area could interfere with the construction of the mold, for example, the placement of water lines within the mold which are preferably located close to the gate. Thus, a larger valve pin head can be accommodated away from the gate.

The use of a larger valve pin head enables the use of a larger surface 45 on the valve pin head and a larger surface 47 on the bore to form the control gap 81. The more “control” surface (45 and 47) and the longer the “control” gap (81) — the more precise control of the melt flow rate and pressure can be obtained because the rate of change of melt flow per movement of the valve pin is less. In Figures 1-3 the size of the gap and

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the rate of melt flow is adjusted by adjusting the width of the gap, however, adjusting the size of the gap and the rate of material flow can also be accomplished by changing the length of the gap, i.e., the longer the gap the more flow is restricted. Thus, changing the size of the gap and controlling the rate of material flow can be accomplished by changing the length or width of the gap.

The valve pin head includes a middle section 83 and a forward cone shaped section 95 which tapers from the middle section to a point 85. This shape assists in facilitating uniform melt flow when the melt flows past the control gap 81. The shape of the valve pin also helps eliminate dead spots in the melt flow downstream of the gap 81.

Figure 3 shows another aspect in which a plug 87 is inserted in the manifold 15 and held in place by a cap 89. A dowel 86 keeps the plug from rotating in the recess of the manifold that the plug is mounted. The plug enables easy removal of the valve pin 41 without disassembling the manifold, nozzles and mold. When the plug is removed from the manifold, the valve pin can be pulled out of the manifold where the plug was seated since the diameter of the recess in the manifold that the plug was in is greater than the diameter of the valve pin head at its widest point. Thus, the valve pin can be easily replaced without significant downtime.

Figures 4 and 5 show additional alternative embodiments of the invention in which a threaded nozzle style is used instead of a support ring nozzle style. In the threaded nozzle style, the nozzle 23 is threaded directly into manifold 15 via threads 91. Also, a coil heater 93 is used instead of the band heater shown in Figures 1-3. The threaded nozzle style is advantageous in that it permits removal of the manifold and nozzles (21 and 23) as a unitary element. There is also less of a possibility of melt leakage where the nozzle is threaded on the manifold. The support ring style (Figures 1-3) is advantageous in that one does not need to wait for the manifold to cool in order to separate the manifold from the nozzles. Figure 5 also shows the use of the plug 87 for convenient removal of valve pin 41.

Figures 6-10 show an alternative embodiment of the invention in which a "forward" shutoff is used rather than a retracted shutoff as shown in Figures 1-5. In the embodiment of Figures 6 and 7, the forward cone-shaped tapered portion 95 of the valve pin head 43 is used to control the flow of melt with surface 97 of the inner bore 20 of nozzle 23. An advantage of this arrangement is that the valve pin stem 102 does not

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restrict the flow of melt as in Figures 1-5. As seen in Figures 1-5, the clearance 100 between the stem 102 and the bore 19 of the manifold is not as great as the clearance 100 in Figures 6 and 7. The increased clearance 100 in Figures 6-7 results in a lesser pressure drop and less shear on the plastic.

5 In Figures 6 and 7 the control gap 98 is formed by the front cone-shaped portion 95 and the surface 97 of the bore 20 of the rear end of the nozzle 23. The pressure transducer 69 is located downstream of the control gap — thus, in Figures 6 and 7, the nozzle is machined to accommodate the pressure transducer as opposed to the pressure transducer being mounted in the manifold as in Figures 1-5.

10 Figure 7 shows the valve pin in solid lines in the open position and Phantom dashed lines in the closed position. To restrict the melt flow and thereby reduce the melt pressure, the valve pin is moved forward from the open position towards surface 97 of the bore 20 of the nozzle which reduces the width of the control gap 98. To increase the flow of melt the valve pin is retracted to increase the size of the gap 98.

15 The rear 45 of the valve pin head 43 remains tapered at an angle from the stem 102 of the valve pin 41. Although the surface 45 performs no sealing function in this embodiment, it is still tapered from the stem to facilitate even melt flow and reduce dead spots.

As in Figures 1-5, pressure readings are fed back to the control system (CPU and  
20 PID controller), which can accordingly adjust the position of the valve pin 41 to follow a target pressure profile. The forward shut-off arrangement shown in Figures 6 and 7 also has the advantages of the embodiment shown in Figures 1-5 in that a large valve pin head 43 is used to create a long control gap 98 and a large control surface 97. As stated above, a longer control gap and greater control surface provides more precise control of  
25 the pressure and melt flow rate.

Figures 8 and 9 show a forward shutoff arrangement similar to Figures 6 and 7, but instead of shutting off at the rear of the nozzle 23, the shut-off is located in the manifold at surface 101. Thus, in the embodiment shown in Figures 8 and 9, a  
30 conventional threaded nozzle 23 may be used with a manifold 15, since the manifold is machined to accommodate the pressure transducer 69 as in Figures 1-5. A spacer 88 is provided to insulate the manifold from the mold. This embodiment also includes a plug 87 for easy removal of the valve pin head 43.

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Figure 10 shows an alternative embodiment of the invention in which a forward shutoff valve pin head is shown as used in Figures 6-9. However, in this embodiment, the forward cone-shaped taper 95 on the valve pin includes a raised section 103 and a recessed section 104. Ridge 105 shows where the raised portion begins and the recessed section ends. Thus, a gap 107 remains between the bore 20 of the nozzle through which the melt flows and the surface of the valve pin head when the valve pin is in the closed position. Thus, a much smaller surface 109 is used to seal and close the valve pin. The gap 107 has the advantage in that it assists opening of the valve pin which is subjected to a substantial force  $F$  from the melt when the injection machine begins an injection cycle. When injection begins melt will flow into gap 107 and provide a force component  $F_1$  that assists the actuator in retracting and opening the valve pin. Thus, a smaller actuator, or the same actuator with less hydraulic pressure applied, can be used because it does not need to generate as much force in retracting the valve pin. Further, the stress forces on the head of the valve pin are reduced.

Despite the fact that the gap 107 performs no sealing function, its width is small enough to act as a control gap when the valve pin is open and correspondingly adjust the melt flow pressure with precision as in the embodiments of Figures 1-9.

Figures 11 and 12 show an alternative hot-runner system having flow control in which the control of melt flow is still away from the gate as in previous embodiments. Use of the pressure transducer 69 and PID control system is the same as in previous embodiments. In this embodiment, however, the valve pin 41 extends past the area of flow control via extension 110 to the gate. The valve pin is shown in solid lines in the fully open position and in Phantom dashed lines in the closed position. In addition to the flow control advantages away from the gate described above, the extended valve pin has the advantage of shutting off flow at the gate with a tapered end 112 of the valve pin 41.

Extending the valve pin to close the gate has several advantages. First, it shortens injection cycle time. In previous embodiments thermal gating is used. In thermal gating, plastication does not begin until the part from the previous cycle is ejected from the cavity. This prevents material from exiting the gate when the part is being ejected. When using a valve pin, however, plastication can be performed simultaneously with the opening of the mold when the valve pin is closed, thus

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shortening cycle time by beginning plastification sooner. Using a valve pin can also result in a smoother gate surface on the part.

The flow control area is shown enlarged in Figure 12. In solid lines the valve pin is shown in the fully open position in which maximum melt flow is permitted. The valve pin includes a convex surface 114 that tapers from edge 128 of the stem 102 of the valve pin 41 to a throat area 116 of reduced diameter. From throat area 116, the valve pin expands in diameter in section 118 to the extension 110 which extends in a uniform diameter to the tapered end of the valve pin.

In the flow control area the manifold includes a first section defined by a surface 120 that tapers to a section of reduced diameter defined by surface 122. From the section of reduced diameter the manifold channel then expands in diameter in a section defined by surface 124 to an outlet of the manifold 126 that communicates with the bore of the nozzle 20. Figures 11 and 12 show the support ring style nozzle similar to Figures 1-3. However, other types of nozzles may be used such as, for example, a threaded nozzle as shown in Figure 8.

As stated above, the valve pin is shown in the fully opened position in solid lines. In Figure 12, flow control is achieved and melt flow reduced by moving the valve pin 41 forward toward the gate thereby reducing the width of the control gap 98. Thus, surface 114 approaches surface 120 of the manifold to reduce the width of the control gap and reduce the rate of melt flow through the manifold to the gate.

To prevent melt flow from the manifold bore 19, and end the injection cycle, the valve pin is moved forward so that edge 128 of the valve pin, i.e., where the stem 102 meets the beginning of curved surface 114, will move past point 130 which is the beginning of surface 122 that defines the section of reduced diameter of the manifold bore 19. When edge 128 extends past point 130 of the manifold bore melt flow is prevented since the surface of the valve stem 102 seals with surface 122 of the manifold. The valve pin is shown in dashed lines where edge 128 is forward enough to form a seal with surface 122. At this position, however, the valve pin is not yet closed at the gate. To close the gate the valve pin moves further forward, with the surface of the stem 102 moving further along, and continuing to seal with, surface 122 of the manifold until the end 112 of the valve pin closes with the gate.



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In this way, the valve pin does not need to be machined to close the gate and the flow bore 19 of the manifold simultaneously, since stem 102 forms a seal with surface 122 before the gate is closed. Further, because the valve pin is closed after the seal is formed in the manifold, the valve pin closure will not create any unwanted pressure spikes. Likewise, when the valve pin is opened at the gate, the end 112 of the valve pin will not interfere with melt flow, since once the valve pin is retracted enough to permit melt flow through gap 98, the valve pin end 112 is a predetermined distance from the gate. The valve pin can, for example, travel 6 mm. from the fully open position to where a seal is first created between stem 102 and surface 122, and another 6 mm. to close the gate. Thus, the valve pin would have 12 mm. of travel, 6 mm. for flow control, and 6 mm. with the flow prevented to close the gate. Of course, the invention is not limited to this range of travel for the valve pin, and other dimensions can be used.

Figures 13-15 show another alternative hot runner system having flow control in which the control of material flow is away from the gate. Like the embodiment shown in Figures 11 and 12, the embodiment shown in Figures 13-15 also utilizes an extended valve pin design in which the valve pin closes the gate after completion of material flow. Unlike the embodiment of Figures 11 and 12, however, flow control is performed using a "reverse taper" pin design, similar to the valve pin design shown in Figures 1-5.

The valve pin 200 includes a reverse tapered control surface 205 for forming a gap 207 with a surface 209 of the manifold (see Figure 14). The action of displacing the pin 200 away from the gate 211 reduces the size of the gap 207. Consequently, the rate of material flow through bores 208 and 214 of nozzle 215 and manifold 231, respectively, is reduced, thereby reducing the pressure measured by the pressure transducer 217. Although only one nozzle 215 is shown, manifold 231 supports two or more like nozzle arrangements shown in Figs. 13-15, each nozzle for injecting into a single or multiple cavities.

The valve pin 200 reciprocates by movement of piston 223 disposed in an actuator body 225. This actuator is described in co-pending application Serial No. 08/874,962. As disclosed in that application, the use of this actuator enables easy access to valve pin 200 in that the actuator body 225 and piston 223 can be removed from the manifold and valve pin simple by releasing retaining ring 240.

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The reverse closure method offers an advantage over the forward closure method shown in Figures 6-9, 11 and 12, in that the action of the valve pin 200 moving away from the gate acts to displace material away from the gate, thereby assisting in the desired effect of decreasing flow rate and pressure.

5 In the forward closure method shown in Figures 6-9, forward movement of the pin is intended to reduce the control gap between the pin and the manifold (or nozzle) bore surface to thereby decrease flow rate and pressure. However, forward movement of the pin also tends to displace material toward the gate and into the cavity, thereby increasing pressure, working against the intended action of the pin to restrict flow.

10 Like the embodiment shown in Figures 6-9, and the embodiment shown in Figures 11 and 12, movement of the valve pin away from the gate is also intended to increase the flow rate and pressure. This movement, however, also tends to displace material away from the gate and decrease pressure. Accordingly, although either design can be used, the reverse taper design has been found to give better control stability in tracking the target pressure.

The embodiment shown in Figs. 13-15 also includes a tip heater 219 disposed about an insert 221 in the nozzle. The tip heater provides extra heat at the gate to keep the material at its processing temperature. The foregoing tip heater is described in United States Patent No. 5,871,786, entitled "Tip Heated Hot Runner Nozzle." Heat  
20 pipes 242 are also provided to conduct heat uniformly about the injection nozzle 215 and to the tip area. Heat pipes such as these are described in U.S. Patent No. 4,389,002.

Figures 13-15 show the valve pin in three different positions. Figure 13 represents the position of the valve pin at the start of an injection cycle. Generally, an injection cycle includes: 1) an injection period during which substantial pressure is  
25 applied to the melt stream from the injection molding machine to inject the material in the mold cavity; 2) a reduction of the pressure from the injection molding machine in which melt material is packed into the mold cavity at a relatively constant pressure; and 3) a cooling period in which the pressure decreases to zero and the article in the mold solidifies.

30 Just prior to the start of injection, tapered control surface 205 is in contact with manifold surface 209 to prevent any material flow. At the start of injection the pin 200 will be opened to allow material flow. To start the injection cycle the valve pin 200 is

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displaced toward the gate to permit material flow, as shown in Fig. 14. (Note: for some applications, not all the pins will be opened initially, for some gates pin opening will be varied to sequence the fill into either a single cavity or multiple cavities). Figure 15 shows the valve pin at the end of the injection cycle after pack. The part is ejected from the mold while the pin is in the position shown in Figure 15.

As in previous embodiments, pin position will be controlled by a controller 210 based on pressure readings fed to the controller from pressure sensor 217. In a preferred embodiment, the controller is a programmable controller, or "PLC," for example, model number 90-30PLC manufactured by GE-Fanuc. The controller compares the sensed pressure to a target pressure and adjusts the position of the valve pin via servo valve 212 to track the target pressure, displacing the pin forward toward the gate to increase material flow (and pressure) and withdrawing the pin away from the gate to decrease material flow (and pressure). In a preferred embodiment, the controller performs this comparison and controls pin position according to a PID algorithm. Furthermore, as an alternative, valve 212 can also be a high speed proportional valve.

The controller also performs these functions for the other injection nozzles (not shown) coupled to the manifold 231. Associated with each of these nozzles is a valve pin or some type of control valve to control the material flow rate, a pressure transducer, an input device for reading the output signal of the pressure transducer, means for signal comparison and PID calculation (e.g., the controller 210), means for setting, changing and storing a target profile (e.g., interface 214), an output means for controlling a servo valve or proportional valve, and an actuator to move the valve pin. The actuator can be pneumatic, hydraulic or electric. The foregoing components associated with each nozzle to control the flow rate through each nozzle are called a control zone or axis of control. Instead of a single controller used to control all control zones, alternatively, individual controllers can be used in a single control zone or group of control zones.

An operator interface 214, for example, a personal computer, is used to program a particular target pressure profile into controller 210. Although a personal computer is used, the interface 214 can be any appropriate graphical or alpha numeric display, and could be directly mounted to the controller. As in previous embodiments, the target profile is selected for each nozzle and gate associated therewith by pre-selecting a target profile (preferably including at least parameters for injection pressure, injection time,

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pack pressure and pack time), programming the target profile into controller 210, and running the process.

In the case of a multicavity application in which different parts are being produced in independent cavities associated with each nozzle (a "family tool" mold), it is preferable to create each target profile separately, since different shaped and sized cavities can have different profiles which produce good parts.

For example, in a system having a manifold with four nozzles coupled thereto for injecting into four separate cavities, to create a profile for a particular nozzle and cavity, three of the four nozzles are shut off while the target profile is created for the fourth.

10 Three of the four nozzles are shut off by keeping the valve pins in the position shown in Figs. 13 or 15 in which no melt flow is permitted into the cavity.

To create the target profile for the particular nozzle and cavity associated therewith, the injection molding machine is set at maximum injection pressure and screw speed, and parameters relating to the injection pressure, injection time, pack pressure and pack time are set on the controller 210 at values that the molder estimates will generate good parts based on part size, shape, material being used, experience, etc. Injection cycles are run for the selected nozzle and cavity, with alterations being made to the above parameters depending on the condition of the part being produced. When satisfactory parts are produced, the profile that produced the satisfactory parts is determined for that nozzle and cavity associated therewith.

This process is repeated for all four nozzles (keeping three valve pins closed while the selected nozzle is profiled) until target profiles are ascertained for each nozzle and cavity associated therewith. Preferably, the acceptable target profiles are stored in computer member, for example, on a file stored in interface 214 and used by controller 210 for production. The process can then be run for all four cavities using the four particularized profiles.

Of course, the foregoing process of profile creation is not limited to use with a manifold having four nozzles, but can be used with any number of nozzles. Furthermore, although it is preferable to profile one nozzle and cavity at a time (while the other nozzles are closed) in a "family tool" mold application, the target profiles can also be created by running all nozzles simultaneously, and similarly adjusting each nozzle profile according the quality of the parts produced. This would be preferable in an

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application where all the nozzles are injecting into like cavities, since the profiles should be similar, if not the same, for each nozzle and cavity associated therewith.

In single cavity applications (where multiple nozzles from a manifold are injecting into a single cavity), the target profiles would also be created by running the nozzles at the same time and adjusting the profiles for each nozzle according to the quality of the part being produced. The system can also be simplified without using interface 214, in which each target profile can be stored on a computer readable medium in controller 210, or the parameters can be set manually on the controller.

Fig. 14 shows the pin position in a position that permits material flow during injection and/or pack. As described above, when the target profile calls for an increase in pressure, the controller will cause the valve pin 200 to move forward to increase gap 207, which increases material flow, which increases the pressure sensed by pressure transducer 217. If the injection molding machine is not providing adequate pressure (i.e., greater than the target pressure), however, moving the pin forward will not increase the pressure sensed by transducer 217 enough to reach the target pressure, and the controller will continue to move the pin forward calling for an increase in pressure. This could lead to a loss of control since moving the pin further forward will tend to cause the head 227 of the valve pin to close the gate and attenuate material flow through and about the gate.

Accordingly, to prevent loss of control due to inadequate injection pressure, the output pressure of the injection molding machine can be monitored to alert an operator when the pressure drops below a particular value relative to the target pressure. Alternatively, the forward stroke of the valve pin (from the position in Figure 13 to the position in Figure 14) can be limited during injection and pack. In a preferred embodiment, the pin stroke is limited to approximately 4 millimeters. Greater or smaller ranges of pin movement can be used depending on the application. If adequate injection pressure is not a problem, neither of these safeguards is necessary.

To prevent the movement of the valve pin too far forward during injection and pack several methods can be used. For example, a control logic performed by the controller 210 can be used in which the output signal from the controller to the servo valve is monitored. Based on this signal, an estimate of the valve pin position is made. If the valve pin position exceeds a desired maximum, for example, 4 millimeters, then the forward movement of the pin is halted, or reversed slightly away from the gate. At

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the end of the injection cycle, the control logic is no longer needed, since the pin is moved to the closed position of Figure 15 and attenuation of flow is no longer a concern. Thus, at the end of the pack portion of the injection cycle, a signal is sent to the servo valve to move the pin forward to the closed position of Fig. 15.

5           Other methods and apparatus for detecting and limiting forward displacement of the valve pin 200 can be used during injection and pack. For example, the pressure at the injection molding machine nozzle can be measured to monitor the material pressure supplied to the manifold. If the input pressure to the manifold is less than the target pressure, or less than a specific amount above the target pressure, e.g., 500 p.s.i., an error  
10   message is generated.

          Another means for limiting the forward movement of the pin is a mechanical or proximity switch which can be used to detect and limit the displacement of the valve pin towards the gate instead of the control logic previously described. The mechanical or proximity switch indicates when the pin travels beyond the control range (for example, 4  
15   millimeters). If the switch changes state, the direction of the pin travel is halted or reversed slightly to maintain the pin within the desired range of movement.

          Another means for limiting the forward movement of the pin is a position sensor, for example, a linear voltage differential transformer (LVDT) that is mounted onto the pin shaft to give an output signal proportional to pin distance traveled. When the output  
20   signal indicates that the pin travels beyond the control range, the movement is halted or reversed slightly.

          Still another means for limiting the forward movement of the pin is an electronic actuator. An electronic actuator is used to move the pin instead of the hydraulic or pneumatic actuator shown in Figures 13-15. An example of a suitable electronic actuator  
25   is shown in co-pending U.S. Serial No. 09/187,974. Using an electronic actuator, the output signal to the servo valve motor can be used to estimate pin position, or an encoder can be added to the motor to give an output signal proportional to pin position. As with previous options, if the pin position travels beyond the control range, then the direction is reversed slightly or the position maintained.

30           At the end of the pack portion of the injection cycle, the valve pin 200 is moved all the way forward to close off the gate as shown in Fig. 15. In the foregoing example, the full stroke of the pin (from the position in Figure 13 to the position in Figure 15) is

approximately 12 millimeters. Of course, different ranges of movement can be used depending on the application.

The gate remains closed until just prior to the start of the next injection cycle when it is opened and moved to the position shown in Fig. 13. While the gate is closed, as shown in Fig. 15, the injection molding machine begins plastication for the next  
5 injection cycle as the part is cooled and ejected from the mold.

Fig. 16 shows time versus pressure graphs (235, 237, 239, 241) of the pressure detected by four pressure transducers associated with four nozzles mounted in manifold block 231. The four nozzles are substantially similar to the nozzle shown in Figures  
10 13-15, and include pressure transducers coupled to the controller 210 in the same manner as pressure transducer 217.

The graphs of Figure 16 (a-d) are generated on the user interface 214 so that a user can observe the tracking of the actual pressure versus the target pressure during the injection cycle in real time, or after the cycle is complete. The four different graphs of  
15 Figure 16 show four independent target pressure profiles ("desired") emulated by the four individual nozzles. Different target profiles are desirable to uniformly fill different sized individual cavities associated with each nozzle, or to uniformly fill different sized sections of a single cavity. Graphs such as these can be generated with respect to any of the previous embodiments described herein.

The valve pin associated with graph 235 is opened sequentially at .5 seconds after  
20 the valves associated with the other three graphs (237, 239 and 241) were opened at .00 seconds. Referring back to Figures 13-15, just before opening, the valve pins are in the position shown in Figure 13, while at approximately 6.25 seconds at the end of the injection cycle all four valve pins are in the position shown in Figure 15. During  
25 injection (for example, .00 to 1.0 seconds in Fig. 16b) and pack (for example, 1.0 to 6.25 seconds in Fig. 16b) portions of the graphs, each valve pin is controlled to a plurality of positions to alter the pressure sensed by the pressure transducer associated therewith to track the target pressure.

Through the user interface 214, target profiles can be designed, and changes can  
30 be made to any of the target profiles using standard windows-based editing techniques. The profiles are then used by controller 210 to control the position of the valve pin. For

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example, Fig. 17 shows an example of a profile creation and editing screen icon 300 generated on interface 214.

Screen icon 300 is generated by a windows-based application performed on interface 214. Alternatively, this icon could be generated on an interface associated with controller 210. Screen icon 300 provides a user with the ability to create a new target profile or edit an existing target profile for any given nozzle and cavity associated therewith. Screen icon 300 and the profile creation text techniques described herein are described with reference to Figures 13-15, although they are applicable to all embodiments described herein.

10 A profile 310 includes (x, y) data pairs, corresponding to time values 320 and pressure values 330 which represent the desired pressure sensed by the pressure transducer for the particular nozzle being profiled. The screen icon shown in Figure 17 is shown in a "basic" mode in which a limited group of parameters are entered to generate a profile. For example, in the foregoing embodiment, the "basic" mode permits  
15 a user to input start time displayed at 340, maximum fill pressure displayed at 350 (also known as injection pressure), the start of pack time displayed at 360, the pack pressure displayed at 370, and the total cycle time displayed at 380.

The screen also allows the user to select the particular valve pin they are controlling displayed at 390, and name the part being molded displayed at 400. Each of  
20 these parameters can be adjusted independently using standard windows-based editing techniques such as using a cursor to actuate up/down arrows 410, or by simply typing in values on a keyboard. As these parameters are entered and modified, the profile will be displayed on a graph 420 according to the parameters selected at that time.

By clicking on a pull-down menu arrow 391, the user can select different nozzle valves in order to create, view or edit a profile for the selected nozzle valve and cavity associated therewith. Also, a part name 400 can be entered and displayed for each  
25 selected nozzle valve.

The newly edited profile can be saved in computer memory individually, or saved as a group of profiles for a group of nozzles that inject into a particular single or multi-  
30 cavity mold. The term "recipe" is used to describe a group of profiles for a particular mold and the name of the particular recipe is displayed at 430 on the screen icon.



To create a new profile or edit an existing profile, first the user selects a particular nozzle valve of the group of valves for the particular recipe group being profiled. The valve selection is displayed at 390. The user inputs an alpha/numeric name to be associated with the profile being created, for family tool molds this may be called a part name displayed at 400. The user then inputs a time displayed at 340 to specify when injection starts. A delay can be with particular valve pins to sequence the opening of the valve pins and the injection of melt material into different gates of a mold.

The user then inputs the fill (injection) pressure displayed at 350. In the basic mode, the ramp from zero pressure to max fill pressure is a fixed time, for example, .3 seconds. The user next inputs the start pack time to indicate when the pack phase of the injection cycle starts. The ramp from the filling phase to the packing phase is also fixed time in the basic mode, for example, .3 seconds.

The final parameter is the cycle time which is displayed at 380 in which the user specifies when the pack phase (and the injection cycle) ends. The ramp from the pack phase to zero pressure will be instantaneous when a valve pin is used to close the gate, as in the embodiment of Figure 13, or slower in a thermal gate (see Figure 1) due to the residual pressure in the cavity which will decay to zero pressure once the part solidifies in the mold cavity.

User input buttons 415 through 455 are used to save and load target profiles. Button 415 permits the user to close the screen. When this button is clicked, the current group of profiles will take effect for the recipe being profiled. Cancel button 425 is used to ignore current profile changes and revert back to the original profiles and close the screen. Read Trace button 435 is used to load an existing and saved target profile from memory. The profiles can be stored in memory contained in the interface 215 or the controller 210. Save trace button 440 is used to save the current profile. Read group button 445 is used to load an existing recipe group. Save group button 450 is used to save the current group of target profiles for a group of nozzle valve pins. The process tuning button 455 allows the user to change the PID settings (for example, the gains) for a particular nozzle valve in a control zone. Also displayed is a pressure range 465 for the injection molding application.

Button 460 permits the user to toggle to an "advanced" mode profile creation and editing screen. The advanced profile creation and editing screen is shown in Figure 18.

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The advanced mode allows a greater number of profile points to be inserted, edited, or deleted than the basic mode. As in the basic mode, as the profile is changed, the resulting profile is displayed.

The advanced mode offers greater profilability because the user can select values  
5 for individual time and pressure data pairs. As shown in the graph 420, the profile 470 displayed is not limited to a single pressure for fill and pack, respectively, as in the basic mode. In the advanced mode, individual (x, y) data pairs (time and pressure) can be selected anywhere during the injection cycle.

To create and edit a profile using advanced mode, the user can select a plurality  
10 of times during the injection cycle (for example 16 different times), and select a pressure value for each selected time. Using standard windows-based editing techniques (arrows 475) the user assigns consecutive points along the profile (displayed at 478), particular time values displayed at 480 and particular pressure values displayed at 485.

The next button 490 is used to select the next point on the profile for editing.  
15 Prev button 495 is used to select the previous point on the profile for editing. Delete button 500 is used for deleting the currently selected point. When the delete button is used the two adjacent points will be redrawn showing one straight line segment.

The add button 510 is used to add a new point after the currently selected point in which time and pressure values are entered for the new point. When the add button is  
20 used the two adjacent points will be redrawn showing two segments connecting to the new point.

Figures 19-23 show another alternative embodiment of an injection molding system. The system includes a manifold 515 having a plurality of nozzles 520 coupled thereto for injecting melt material into a plurality of cavities 525. Alternatively, the  
25 nozzles can also inject into a single cavity. In Figure 19, only one nozzle 520 is shown but the following description applies to all nozzles coupled to manifold 515.

As in previous embodiments, each nozzle in the system includes a pressure transducer 530 associated therewith for sensing the pressure of the melt material in the manifold which thereby gives an indication of rate of meltflow through nozzle 520 and  
30 into cavity 525 with respect to each injection molding nozzle. Mold cavity 525 is formed by mold halves 526 and 527, which are separated to eject the molded part formed

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in cavity 525 after the injection cycle. As in previous embodiments, the pressure transducer can also be located in the nozzle, the manifold, or the cavity.

As in previous embodiments, a controller 535 receives signals from pressure transducers 530 coupled to each nozzle 520 (only one of which is shown). The  
5 controller 535 controls solenoid valve 540 which controls the movement of a piston in actuator 545 which is coupled to and acts to reciprocate the valve pin 550 to open and close gate 555 to cavity 525.

The controller also sends a signal to servo valve 560A which controls actuator 560 which in turn controls the movement of a ram 565, and further controls solenoid  
10 valve 570 which is coupled to another actuator 575 which controls a valve 580 which is adapted to open and close a manifold channel 585 which leads to nozzle 520. Each injection nozzle coupled to manifold 515 (not shown) includes the foregoing actuators 545, 575 and 560 and ram 565 and solenoid valves 540 and 570 and servo valve 560A associated therewith for controlling flow from each nozzle.

15 The actuators are mounted in a clamp plate 595 which also includes an opening 600 that receives an inlet bushing 610 threadably mounted to the manifold 515. The inlet bushing 610 receives a nozzle 590 from an injection molding machine. The injection molding machine can be, for example, a reciprocating or non-reciprocating extruder. The injection molding machine nozzle 590 feeds melt material into the central  
20 bushing 610 into a central channel 620 which branches off via a plurality of channels 585 and 630 (and others not shown) to a corresponding plurality of injection molding nozzles 520.

The foregoing embodiment is similar to previous embodiments in that pressure transducer 530 is used to measure pressure indicative of flow rate of melt material into  
25 cavity 525 during the injection cycle. (The actuators described herein are hydraulic actuators, however, pneumatic or electric or other types of actuation can also be used.) Also, as in previous embodiments, a controller 535 compares the pressure sensed by the pressure transducer to target values of a target profile and issues control signals to increase or decrease pressure to track the target profile for each nozzle.

30 In previous embodiments the controller controlled the position of a valve pin to regulate flow rate independently at each gate during injection. The foregoing embodiment also enables the flow rate of plastic to be controlled independently through

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each nozzle 520 and each gate during injection. However, in the embodiment shown in Figures 19-23, a valve pin is not used to control flow rate as in previous embodiments. Rather, valve pin 550 is used only to open and close gate 555.

In the foregoing embodiment, ram 565 and well 640 are used to regulate the flow  
5 of melt material through nozzle 520 and into cavity 525 in the following manner.

At the start of the injection cycle, valve gate 555 is closed by valve pin 550 and valve 580 is opened to permit flow through manifold channel 585 (see Figure 20). The injection molding machine nozzle 590 injects melt material through the inlet bushing 610 into the manifold 515, such that it fills well 640 (see Figure 20). The valve pin 550 is  
10 still in the closed position while the well 640 is being filled. Ram 565 is in a predetermined adjustable retracted position to permit a specific volume of melt material to gather in well 640 (see Figure 21). Figure 21 shows the system ready to inject melt material into cavity 525.

The controller 535 then signals the servo valve 540 to cause actuator 545 to  
15 retract valve pin 550 and open gate 555, while also signaling servo valve 570 to cause actuator 575 to close valve 580 and shut off manifold channel 585. Closing valve 580 when injecting into the cavity prevents backflow of material through channel 585. This position is shown in Figure 22.

The controller then signals actuator 560 to move ram 565 forward to inject  
20 material from the well 640 through the nozzle 520 and into the cavity 525. During this time, the controller controls the velocity at which the ram moves forward, according to the pressure sensed by pressure transducer 530, in relation to a target pressure profile. Accordingly, if the pressure transducer 530 senses a pressure that is below the target pressure for that particular time during the injection cycle, the controller 535 signals the  
25 actuator 560 to increase the velocity of the ram 565, conversely, if the pressure sensed is greater than the target pressure, the controller will control the actuator to decrease the velocity of the ram forward. When the ram reaches its lowermost position, the cavity 525 is full and the gate is closed (see Figure 23). Alternatively, ram 565 can be velocity controlled by using a linear transducer to monitor ram position. If so, at the end of  
30 injection, the ram is not bottomed out, and control can be transferred to the pressure transducer 530 during pack.

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As stated above, a reciprocating or non-reciprocating extruder can be used. If a non-reciprocating extruder is used, plastication into the manifold can be continuous, and the valve 580 is used to shut off the manifold channel 585 during injection so that during this time no plastic can flow through the manifold channel. When well 640 is filled with melt material, plastication in the non-reciprocating extruder can be stopped until the next cycle.

As in previous embodiments described herein, preferably a PID algorithm is used to control the actuator 560 to track the target profile. The target profile can be created in the same manner as described above with respect to previous embodiments.

Using the embodiment shown in Figures 19-23, the flow rate of plastic through each gate is controlled independently. Additionally, the use of well 640 enables one to control the specific volume of plastic injected into each cavity 525, which leads to part-to-part consistency, especially when molding in multi-cavity applications in which each cavity 525 is an identical part. By altering the position of ram 565 when injecting melt material into well 640, the volume of material in well 640 can be controlled, thereby controlling the volume of material into cavity 525.

Figures 24-28 show an alternative embodiment in which a load cell 140 is used to sense the melt pressure acting on the face 142 of valve pin 41. Where possible, reference characters are used that refer to elements common to Figure 1. As in previous embodiments, an actuator 49 is used to translate the valve pin 41 toward and away from the gate. The actuator 49 includes a housing 144 and a piston 146 slidably mounted within the housing. The actuator is fed by pneumatic or hydraulic lines 148 and 150. Other actuators, for example, electrical actuators may also be used.

The valve pin 41 is mounted to the piston 146 so that valve pin translates through the injection nozzle 23 with movement of the piston. The valve pin is mounted to the piston via a pin 152. The pin 152 is slotted so that a clearance 154 exists in which the valve pin can translate with respect to the pin 152 and piston 146. The valve pin bears against a button 156 on the load cell 140. The load cell 140 is mounted via screws 158 to the piston. Thus, as shown in Figure 26, a force F2 acting on the valve pin will cause the load button 156 to depress. Excitation voltages or other types of signals which indicate the proportionate force on the load button 156 are carried through cable 160 and fed to a controller 151.

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In operation, as seen in Figure 24, the melt material is injected from an injection molding machine nozzle 11 into an extended inlet 13 mounted to a manifold 15 through respective injection molding nozzles 21 and 23 and into mold cavities 162 and 164. In the embodiment shown, a multi-cavity mold is shown in which nozzles 21 and 23 inject melt material to form different size molded parts in cavities 162 and 164, respectively. As stated above with respect to the embodiment shown in Figure 1, a mold cavity with multiple gates can be used, or multiple mold cavities with cavities having the same size can be used.

When the valve pin 41 is retracted to permit melt material to be injected into the cavity 162, the melt pressure will act on the face of the valve pin 142 with the resulting force being transmitted through the shaft of the valve pin to the load sensor 140 (see Figures 26-27). Thus, the load ( $F_2$ ) sensed by load cell 140 is directly related to the melt flow rate into the melt cavity.

Shear stresses caused by the melt streaming downward over the valve pin will tend to reduce the pressure sensed by the load cell but such stresses are typically less than the nominal load due to the melt pressure. Thus, the resultant force  $F_2$  will tend to compress the valve pin toward the load cell, with the possible exception of the initial opening of the valve, and the load cell provides an accurate indicator of the melt pressure at the gate. If the application results in shear stresses exceeding  $F_2$ , the load cell can be pre-loaded to compensate for such stresses.

Similar to previous embodiments described above, the signal transmitted through cable 160 is compared by controller 151 with a target value of a target profile and the controller adjusts the position of the valve pin accordingly to increase or decrease flow rate. In this embodiment, the target profile is also a time versus pressure profile, but the pressure is the a result of the force of the pin on the load cell, as opposed to previous embodiments in which a pressure transducer directly senses the force of the flow of the melt material. The profile is created in similar fashion to the embodiments described above: running the process and adjusting the profile until acceptable parts are produced.

The valve pin controls the flow rate through the gate using a tapered edge 155 to form a control gap 153 close to the gate. It should be noted, however, that any of the other valve pin designs described herein can be used with the load cell 140. Accordingly, when the pressure sensed by the load cell is less than the target pressure on

the target profile, the controller 151 signals the actuator to retract the valve pin to increase the size of the control gap 153 and, consequently, the flow rate. If the pressure sensed by the load cell 140 is greater than the target pressure, the controller 151 signals the actuator to displace the valve pin toward the gate to decrease the size of the control gap 153 and consequently, the flow rate.

The use of the load cell has an additional application shown in Figure 27A. In a single cavity multiple gate system it is often desirable to open gates in a cascading fashion as soon as the flow front of the melt material reaches the gate. When melt material 166 has flowed into the gate area of the valve pin, a force F3 from the melt in the cavity is exerted on the face 142 of the valve pin.

In this way, gates can be sequentially opened in cascading fashion by sensing the force of the melt pressure on the face of the valve pin when the valve pin is closed. Given typical gate diameters of .2 inches and melt pressures of 10,000 psi, the resulting force of 300 pounds is readily measured by available load sensors, since the force of the cell equals the area of the gate times the pressure at the gate. Thus, this melt detection can then be used to signal the opening of the gate as in the sequential valve gate. This assures that the gate does not open prematurely.

Figures 28A and 28B show an alternative embodiment in which the sheer stress on the valve pin is reduced. The nozzle 21 is designed to include a channel for melt flow 168 and a bore 170 through which the valve pin reciprocates. As such, the flow does not cause any axial sheer stress on the valve pin and thus reduces errors in pressure sensing. An indent 172 is provided in the nozzle 21 so that side load on the valve pin is reduced, i.e., to equalize pressure on both sides of the valve pin. An additional benefit to the configuration shown in Figures 28A and 28B is that since the flow of material is away from the valve pin, the valve pin does not "split" the flow of material, which can tend to cause part lines or a flow streak on the molded part.

Figure 29 shows another alternative embodiment of the present invention similar to Figure 19. As in Figure 19, a ram 565 is used to force material from well 640 into cavity 525 at a controlled rate. The rate is controlled by signals sent from controller 535 to servo valve 560A, which in turn controls the velocity at which actuator 560 moves ram 565 forward.

- 30 -

In Figure 29, actuator 560 is shown in more detail including piston 564, actuator chamber 566, and hydraulic lines 561 and 562 controlled by servo valve 560A. Energizing hydraulic line 561 and filling chamber 566 causes piston 564 and ram 565 to move forward and displace material from well 640 through channel 585 and nozzle 520, and into cavity 525. In the embodiment of Figure 19, the controller controls the rate at which the ram injects material according to signals received by pressure transducer 530, compared to a target profile. In the embodiment of Figure 29, pressure transducer 530 has been removed in favor of pressure transducer 563 mounted along hydraulic line 561 which leads to chamber 566. The pressure transducer 560 senses the hydraulic fluid pressure in line 561 and sends a proportional signal to the controller 535. Since the pressure of the hydraulic fluid entering chamber 566 is directly related to the rate at which the ram 565 moves forward, and the rate at which the ram moves forward is directly related to the rate of material flow into the cavity 525, the pressure sensed by pressure transducer 560 is directly related to the rate of material flow into the cavity 525, and can be used to control the material flow rate.

Accordingly, as in previous embodiments, a target profile is created that has been demonstrated to generate acceptable molded parts. In the embodiment of Figure 29, however, the target profile represents target values of the hydraulic pressure sensed by pressure transducer 563, as opposed to directly sensing the material pressure. In operation, the controller compares the pressure signal sensed from pressure transducer 563 to the target pressure profile for gate 555. If the pressure sensed is too low, the controller will increase the hydraulic pressure in line 561 (which increases the velocity of the ram which increases flow rate of the material), if the pressure is too high the controller will decrease the hydraulic pressure (which decreases the velocity of the ram which decreases the rate of material flow).

The target pressure profile of the hydraulic fluid will appear similar to a conventional material profile, since the pressure of the hydraulic fluid will rise rapidly during the injection portion of the cycle, level off during the pack portion of the cycle, and go to zero pressure as cycle ends the valve pin 550 closes.

Although only one injection nozzle 520 and cavity 525 is shown, there is a like arrangement associated with each injection nozzle of actuators 575, 565, 545, as well as solenoid valves 540 and 570 and servo valve 560, to independently control the melt



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flowing from each gate, according to the target profile created for that gate. Also, although a single cavity 525 is shown, each nozzle may inject to multiple cavities or a single cavity mold. Only a single controller 535, however, is needed to control all the nozzles associated with manifold 515.

5           Using the foregoing arrangement of Figure 29, as in previous embodiments, the material flow from each nozzle of the manifold can be controlled independently.

Figure 30 shows another alternative embodiment of the present invention. The embodiment of Figure 30 is substantially the same as the embodiment shown in Figure 13 with the exception that pressure transducer 217 has been moved from manifold 231 to  
10   inside the mold half 650 which, together with mold half 660, forms mold cavity 670 in which the molded part is formed. Accordingly, in this embodiment, the target profile represents target values of the pressure sensed by pressure transducer 217 inside the cavity opposite the gate 211.

The operation of the embodiment of Figure 30 is the same as that described in the  
15   embodiment shown in Figure 13 in terms of target profile creation and use of valve pin 200 to control the material flow (interface 214 is not shown Figure 30 but can be used). However, placing the pressure transducer in the cavity offers several advantages, for example, in the cavity the pressure transducer 217 is not exposed to the high temperatures generated by the manifold, as in Figure 13. Also, the presence of the  
20   pressure transducer in the manifold may slightly disrupt material flow in the manifold. Another consideration in choosing whether to mount the transducer in the mold or in the manifold is whether the mold geometry permits the transducer to be mounted in the mold.

Figure 31 is another alternative embodiment of the present invention that is  
25   similar to Figure 13 (like reference characters are used wherever possible). Target profile creation as well as the flow control operation by valve pin 200 is substantially the same as described above. Figure 31, however, does not include a pressure transducer 217 as shown in Figure 13 to directly sense the flow of melt material into the cavity. Rather, similar to the embodiment shown in Figure 24, the arrangement shown in Figure  
30   31 performs flow control by sensing the material pressure F2 exerted by the melt material on the valve pin.

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In Figure 24 measuring the load on the valve pin was performed using a load cell 140, however, in Figure 31, it is performed by pressure transducers 700 and 710 mounted along hydraulic lines 720 and 730 which lead to actuator chambers 740 and 750, respectively. Energizing lines 720 and 730 and filling actuator chambers 740 and 750, enables axial movement of piston 223, thereby moving valve pin 200 and affecting the flow rate of the material into the cavity 760 as described above.

Pressure transducers 700 and 710 sense a differential pressure which is directly related to the force exerted on valve pin 200, which is directly related to the flow rate of the material. For example, when the material flow causes a force  $F_2$  to act on valve pin 200, the force relates up the valve pin to the piston, which in turn tends to increase the pressure in chamber 740 and line 720 and decrease the pressure in chamber 750 and line 730, directly causing a change in the difference in the pressures sensed by the transducers 700 and 710. Accordingly, the differential pressure is directly related to the flow rate of the material into the cavity.

Once an acceptable target profile of differential pressure is developed using techniques described above, the controller will cause the servo valve 212 to track this target profile by altering the position of the valve pin to change the flow rate of the material and track the differential pressure target profile. For example, if the differential pressure is too high (e.g., the pressure sensed by transducer 700 is higher than the pressure sensed by transducer 710 by an amount greater than the target differential pressure) the controller will cause servo valve to retract the valve pin to reduce the flow rate, thereby reducing the force  $F_2$  on the valve pin, thereby decreasing the pressure in chamber 740 and line 720, thereby decreasing the pressure sensed by transducer 700, thereby decreasing the difference in pressure sensed by transducers 700 and 710. Note, in certain applications the differential pressure may be negative due to the sheer force of the material on the valve pin, this however will not affect the controller's ability to track the target profile.

As in the embodiment shown in Figure 24, the embodiment shown in Figure 31 offers the advantage that it is not necessary to mount a pressure transducer in the mold or the manifold. As in all previous embodiments, the embodiment shown in Figure 31 enables the material flow from each nozzle attached to the manifold to be independently profileable.

Figure 32 shows an entire control system arrangement 800 which can be used with any of the embodiments described above in Figures 1-31. In Figure 32, the system is shown with the manifold, nozzle and mold arrangement shown in Figure 1, and like reference characters are used wherever possible.

5 Similarly to Figure 1, the control system 800 includes a manifold 15 for dispensing material injected from machine nozzle 11 through injection molding nozzles 21 and 23 into a mold cavity 5. As explained above, each nozzle has a valve pin 41a and 41b associated therewith that is used to independently control the rate of material flow through nozzles 21 and 23 and into cavity 5. Servo valves 802 are controlled by  
10 controller 804 to in turn control actuators 49(a) and 49(b) to alter the respective positions of each valve pin according to a target pressure profile associated with that particular servo-valve, valve pin, injection nozzle, pressure transducer and gate (herein referred to as a "control zone"). As explained above, the valve pin of a control zone adjusts the flow rate of the material flowing to the gate of the control zone so that the pressure read  
15 by the pressure transducer in the control zone tracks the target values of pressure in the target profile for that control zone, throughout the injection cycle.

Real-time control is provided via feedback from pressure transducers 69(a) and 69(b) which record material pressure values, feed them back into controller 804, which compares the pressure values to target values throughout the injection cycle. The  
20 controller then displaces the valve pins, according to whether an increase or a decrease in material pressure is called for by the target profiles. According to one preferred embodiment, the target profiles are executed by, for example, a PID algorithm stored in the controller 804.

The controller 804 can include a programmable logic controller (PLC) to provide  
25 input/output connections. For example, the PLC can be used to capture the material pressure data from the pressure transducers 69(a) and 69(b), and also provide control signals to servo valves 802. The controller 804 is connected to both the servo valves 802 and the hydraulic power source 808 to monitor and control the hydraulic power source. The operator interface 805 is, for example, the same as interface 214 described with  
30 reference to Figures 14-18 above.

A complete control system 800 is shown in Figure 32 which includes an injection molding machine 806, which injects material into manifold 15 via nozzle 11. The

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machine includes a reciprocating screw 809 which is used to force material out of the injection molding machine fed from hopper 816. The screw is attached to a hydraulic actuator 818 which is controlled by the machine controller 812 which includes an operator interface 814. Pressurized hydraulic fluid is supplied to the actuator via an injection molding machine hydraulic power unit 810. Using the operator interface, a user can set injection time, injection pressure, pack pressure, pack time, etc., for any given injection cycle.

In addition to controlling the rate of material flow through each control zone, the controller 804 also interfaces with the injection molding machine in several ways. The controller 804 is coupled to the injection molding machine controller 812. The injection molding machine controller 812 can provide several different signals to the controller 804. For example, the controller 812 can indicate to the controller 804 that all gates and guards on the injection molding machine are closed and the machine 806 is in a state in which injection can occur. This signal should be received while the controller 804 is performing its controlling functions during the injection cycle.

The injection molding machine also can include an emergency stop button which could be wired to the controller 804 in which the controller 804 would not perform controlling operations if the emergency stop is indicated. The controller 812 also can provide a signal to the controller 804 to indicate the start of injection based on physical characteristics of the injection molding machine. This signal is to remain high until the end of injection and pack. Accordingly, the controller 804 can use this "start of injection" signal to begin control according to the target profiles. For example, the rising edge of the start of injection signal can indicate to the controller 804 that the start of injection has begun.

A start of injection signal can also be provided to controller 804 by a linear position transducer 820 indicating that the screw 809 is in a position in which injection has begun. Another way to provide a start of injection signal is to measure the pressure of the material in the machine nozzle 11 by a pressure transducer 820 coupled to controller 804. Basing the start of injection signal on these physical readings associated with the injection molding machine can insure that adequate pressure is being supplied to the manifold when the controller 804 begins executing the target profiles.

It is also desirable to provide an end of injection signal to the controller 804. One way to provide such a signal is to detect the falling edge of the injection molding machine “on” signal described above. The end of injection signal can also be indicated by the rising edge of an “injection molding machine injection complete” signal provided  
5 by controller 812. Lastly, the controller 804 itself can provide an end of injection signal, when all profiles have been completed. Thus, the end of injection signal is used to indicate to either the injection molding machine 806, the controller 804 or both, that the injection process is completed and all injection functionality should be discontinued.

The injection molding machine 812 can also provide a signal to the controller 804  
10 that the injection molding machine has transitioned from “injection pressure” to “pack pressure.” According to one embodiment, controller 804 can use this signal to determine when the injection molding machine is transitioning and determine if said transitioning is prior to the target profiles transitioning to a pack pressure. This early transitioning of the injection molding machine can result in a cavity or cavities not filling entirely. Thus,  
15 controller 804 could use this signal to generate a warning message via operator interface 805 if early transitioning occurs.

The injection molding machine controller 812 can also provide a signal to the controller 804 that the injection molding machine has reached the end of its injection forward sequence (i.e., that the screw 809 has reached its forward-most position). The  
20 controller 804 could use this signal to alert an operator via operator interface 805 if the injection molding machine has stopped injecting before all of the target profiles have been completed. This signal can also be used to indicate that cycle times are not being minimized if the injection molding machine is still injecting after the controller 804 has completed all target profiles during the injection cycle.

25 The injection molding machine controller 812 may also provide a signal as to when the pre-decompression (when the screw 809 is reset prior to plastication), or decompression (when the screw 809 is reset after plastication), is complete. The signal can be used to indicate when the controller 804 can close valve pins 41(a) and 41(b) (i.e., withdraw the valve pins 41(a) and 41(b) until the manifold channels are closed) to be in  
30 position for the next injection cycle. If this signal is not provided, the controller will simply set a period of time from the end of the injection cycle to close the valve pins 41(a) and 41(b).

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The controller 804 also can communicate signals to the injection molding machine controller 812. The controller output interface 805 can also include an emergency stop as described above with respect to the injection molding machine. This emergency stop signal can be sent to the controller 812 and will act to halt the injection molding machine. The controller 804 can also provide a signal indicating to the controller 812 that the controller 804 is resident and must be interfaced with. The signal can be carried, for example, by a jumper cable connecting both controllers. The jumper will complete an input circuit with the injection molding machine indicating that the controller 804 is resident.

10       The controller 804 can also provide a "ready" signal to controller 812 indicating that the hydraulic power source 808 is ready and that no alarms are present that would inhibit injection.

Controller 804 can also provide a signal to controller 812 indicating that all target profiles being executed by controller 804 have transitioned from the fill stage of injection to the pack and hold stage. In one embodiment, the injection molding machine uses the signal to unload the high volume pumps no longer necessary in the pack and hold stages. Another use of the signal is to trigger the start of gas injection for a gas assist application. The target profile of the injection cycle would end after injection of melt material after which gas is used to pack up the part.

20       The controller 804 can also provide a signal indicating that all the target profiles have been completed. The signal can then be used to abort the injection molding machine cycle and thus reduce wasted cycle time. This signal can also be used to indicate that cycle times are not being minimized if the injection molding machine is still injecting after the target profiles are completed. Accordingly, this information could be used to reset the injection molding machine cycle time. Controller 804 can also provide a signal to the injection molding machine indicating that there was a control problem during the injection cycle and therefore a high likelihood that the parts could be faulty.

30       The system 800 also includes cavity pressure transducers 824 and 826. These transducers provide useful information related to the molding process. The transducers can be used to monitor and display cavity pressure via pressure profile curves for each control zone. This information can be used for trouble shooting to determine if any process changes have occurred. The information can also be used for statistical process

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control to ensure that the process stays within determined operating limits. For example, pressure readings from these pressure transducers can establish acceptance criteria for peak pressure, pack pressure, average pressure, area under the pressure curve, or other pressure values during the injection cycle. Parts created during a cycle in which these  
5 criteria were not met can be rejected, or at least a notification can be generated at the operator interface 805 to warn the operator.

The use of cavity transducers 824 or 826 provides greater control of the process. For example, if one of the transducers consistently registers too high or too low a pressure at a particular point in the injection cycle, the target profile associated with that  
10 control zone can be altered accordingly, using operator interface 805. This can be especially useful in a large part having multiple gates. Placing cavity transducers at multiple points along the cavity provides information on how the part fills during the process and, if the part is not filling properly, on which target profiles of which control zones should be altered and how they should be altered.

15 Transducers 824 and 826 can also be used to trigger switchover in the target profiles (and/or the injection molding machine) from injection pressure to pack pressure. In the embodiments described above switchover from injection pressure to pack pressure is determined by the target profiles according to time, however, using the pressure transducers, a set point pressure can be established at which time the target profile  
20 switches to the "pack" area of the profile, independent of time. This can be done for each target profile separately, as there would be a cavity pressure transducer associated with each control zone. This variable can also be used to control when the injection molding machine switches from injection pressure to pack pressure.

Switchover can also be controlled by placing transducers at either end of cavity 5.  
25 When the pressure transducers detect material pressure at the end of the cavity, the controller 804 can switch the control zone (or zones) associated with that end of the cavity to the "pack" portion of the target profile. This method of controlling "switchover" can account for variations in material viscosity which can cause the part to fill more quickly or slowly, thus, making a time-based "switchover" inexact.

30 Controlling "switchover" is also useful in multiple cavity applications, as shown in Figure 35. In a mold have multiple like cavities 5a and 5b, ideally the controller 804 would "switchover" each control zone (one for each cavity when each cavity has a single

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gate) from injection to pack at the same point in time during the injection cycle. Material and flow variations in the multiple cavities, however, may cause the filling rates to be slightly different from one cavity to the next. Using a pressure transducer in each cavity 5a and 5b to trigger switchover independently for each control zone, as described above, 5 compensates for these variations and can improve the repeatability of the process. Alternatively, the cavity pressure transducer can be used to "tweak" each target profile to create uniform cavity pressure readings (and uniform parts) from each cavity. In the multi-cavity application the pressure transducer can be located adjacent the gate similarly to Figure 32, or at an end of each cavity 5a and 5b as shown. As described above, either 10 location can be used to control switchover.

The cavity pressure transducers can also be used to determine the end of the pack period, unlike previous embodiments in which the profile itself dictates the end of pack at a particular time after the start of injection. Again referring to Figure 35, transducers located at the end of the cavities 5a and 5b, can be used to determine the end of the pack 15 period for individual cavities (or a single cavity) by indicating when the pressure at the end of the cavity reaches a particular value during pack indicating that the part is filled. Thus, the end of pack can be independently set in each control zone according to when a particular pressure is detected. If an extended valve pin is used (see Figures 11-15), the valve pins can be closed according to this pressure-based end of pack determination. 20 The use of pressure to determine end of pack ensures consistent part weight by compensating for flow variations within the cavity or cavities which may change from shot to shot.

For cascade molding, cavity pressure transducers can be used to indicate the arrival of the material flow front at a gate downstream of the initial gate opened. Once 25 the flow front is past the downstream gate, the cavity pressure transducer will see a rise in pressure. The controller 804 can then start the injection at the next gate based on a determined pressure set point measured by the cavity pressure transducer.

As shown in Figure 32, the controller 804 also interfaces with machine nozzle pressure transducer 822. As explained above, this pressure can be used by the controller 30 804 to start the target profiles, and also be used to ensure that the supply pressure is high enough to run the process. If the injection molding machine 806 is supplying an



inadequate pressure, a signal could be generated by the controller 804 and displayed on the operator interface 805.

The controller also interfaces with a linear transducer 820 that measures the position of the ram 809 and can be used as an indicator of the volume of material  
5 injected into the part. "Switchover" from injection pressure to pack pressure in both the target profiles and the injection molding machine (described above) can also be based on a set point value associated with linear transducer 820 indicating that the proper volume of material has been injected into the mold.

Figure 33 shows an alternative embodiment similar to the system shown in  
10 Figure 32. In this embodiment, however, the hydraulic power source 808 has been eliminated and servo valves 802 are connected directly to the injection molding machine hydraulic power unit 810. Thus, hydraulic power to servo valves 802 used to manage the flow of pressurized fluid to actuators 49(a) and 49(b) comes directly off the injection molding machine power unit 810, and this configuration saves the expense of having a  
15 separate power source 808 to supply servo valves 802. The system is the same as the system shown in Figure 32 in all other respects.

Several other alternative configurations are possible with respect to Figure 33. For example, an accumulator (not shown) can also be connected to the hydraulic power unit 810 to ensure a steady supply of pressurized fluid to servo valves 802 of which there  
20 is a single servo valve for each actuator 49(a) and 49(b). Also, the servo valve 802 may be mounted to the injection molding machine directly or to the mold as shown.

Figure 34 shows another alternative embodiment of a injection molding system similar to the system shown in Figure 33. In Figure 34, however, the controller 804 and operator interface 805 has been integrated as part of the injection molding machine  
25 controller 830 and 832. Controller 830 and operator interface 832 perform the functions of controllers 804, 812, and operator interfaces 805 and 814 of Figures 32 and 33. This integration simplifies the system and reduces the hardware in the system.

The integration can be performed by simply mounting the programmable controller described above within controller 804 into the injection molding machine  
30 control cabinet which contains controller 812. In such a case the input and output functions performed by controller 804 would still be performed by the same PLC. Alternatively, a single PLC or other type of controller can be used to interface all

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injection molding machine controller functions and functions performed by controller 804. The operator interface 832 performs the functions of both operator interfaces 805 and 814 of Figures 32 and 33 and interfaces directly with the PLC that controls servo valves 802 for menus, set-up displays of process readings, and other functions.

- 5           The hydraulics in Figure 34 are the same as in Figure 33 with servo valves 802 being supplied hydraulic power by injection molding machine hydraulic power unit 810. Alternatively, separate hydraulic power sources can be used as shown in Figure 32.

Having thus described certain embodiments of the present invention, various alterations, modifications, and improvements will readily occur to those skilled in the art.

- 10       Such alterations, modifications, and improvements are intended to be within the spirit and scope of the invention. For example, in the embodiments shown in Figures 31-33, although only two gates are shown to a single cavity 5, more gates (and associated nozzles, valve pins, actuators and servo valves, i.e., control zones) may be used which gate into one or more cavities.

- 15           Additionally, servo valves 802 are shown in Figures 32-35 (and previous embodiments), however, the invention is not so limited and other types of valves such as proportional valves may be used. Also, although hydraulic actuators 49a and 49b are used in Figures 32-35 (and previous embodiments), pneumatic or electronic actuators can be used to control the valve pins (for example, the electronic actuators disclosed in
- 20       co-pending patent application serial number 09/187,974 entitled ELECTRONIC ACTUATOR FOR PIN). Thus, the invention is not limited to a particular type of actuator. Further still, although a hydraulic-powered injection molding machine is shown in Figures 32-35, the invention is not limited to a particular type of injection molding machine. For example, an electronic injection molding machine could be used.

- 25           Accordingly, the foregoing description is by way of example only, and not intended to be limiting. The invention is limited only as defined in the following claims and the equivalents thereof.

CLAIMS

1. An injection molding system comprising:  
an injection molding machine including a hydraulic power source;  
5 a manifold for distributing material injected from said injection molding machine  
to a plurality of gates leading to one or more mold cavities; and  
a controller to individually control respective rates at which material is injected  
through said gates during an injection cycle, wherein the controller is coupled to the  
hydraulic power source and the hydraulic power source supplies hydraulic power to both  
10 the injection molding machine and to control said respective rates.
2. The injection molding system of claim 1, further comprising a plurality of  
actuators respectively associated with said plurality of gates, wherein said hydraulic  
power source supplies hydraulic power to said plurality of actuators.  
15
3. The injection molding system of claim 2, further comprising a plurality of  
valve pins, wherein each actuator is coupled to one of said valve pins to axially displace  
said valve pins to alter a rate of material flow through a gate associated therewith.
- 20 4. The injection molding system of claim 4, further comprising a plurality of  
servo valves coupled to said hydraulic power source, wherein said servo valves are  
controlled by said controller to regulate the flow of hydraulic fluid to said actuators.
5. An injection molding system comprising:  
25 an injection molding machine; and  
a manifold for distributing material injected from said injection molding machine  
to a plurality of gates leading to one or more mold cavities, wherein the injection  
molding machine includes a controller to individually control respective rates at which  
material is injected through said gates during an injection cycle.  
30
6. The injection molding system of claim 5, wherein the injection molding  
machine also includes a controller to control a rate at which the injection molding  
machine injects material into said manifold.

7. The injection molding system of claim 6, wherein a same controller is used to individually control respective rates at which material is injected through said gates during an injection cycle and to control a rate at which the injection molding  
5 machine injects material into said manifold.

8. The injection molding system of claim 5, wherein the controller controls the respective rates within the manifold.

10 9. The injection molding system of claim 5, wherein the controller controls the respective rates within individual injection nozzles coupled to the manifold that each lead to a gate.

10. The injection molding system of claim 6, wherein the injection molding  
15 machine further comprises an operator interface used to set parameters related to the respective rates at which material is injected through said gates during an injection cycle and the rate at which the injection molding machine injects material into said manifold.

11. An injection molding system comprising:  
20 an injection molding machine;  
a manifold for distributing material injected from plurality of a nozzles of said injection molding machine to a plurality of gates leading to one or more mold cavities;  
a controller to individually control respective rates at which material is injected through said gates during an injection cycle; and  
25 a pressure transducer coupled to the nozzle of said injection molding machine, wherein said controller receives pressure data from said pressure transducer.

12. The injection molding system of claim 11, wherein the controller uses said pressure data to determine when the injection molding machine has started injection.  
30

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13. The injection molding system of claim 11, wherein the controller controls each respective rate based on a sensed condition related to the rate of material flow through the gate associated therewith.
- 5        14. The injection molding system of claim 13, wherein the controller controls each respective rate based on target profile of said sensed condition associated with each gate.
- 10        15. An injection molding system comprising:  
an injection molding machine;  
a manifold for distributing material injected from a plurality of nozzles of said injection molding machine to a plurality of gates leading to one or more mold cavities;  
a controller to individually control respective rates at which material is injected through said gates during an injection cycle; and  
15        a position transducer coupled to a screw of said injection molding machine, wherein said controller receives position data of said screw from said position transducer.
- 20        16. The injection molding system of claim 15, wherein the controller uses said position data to determine when the injection molding machine has started injection.
- 25        17. The injection molding system of claim 15, wherein the controller uses said position data to determine when to switchover each respective rate from injection to pack.
- 30        18. The injection molding system of claim 15, wherein the controller controls each respective rate based on a sensed condition related to the rate of material flow through the gate associated therewith.
19. The injection molding system of claim 18, wherein the controller controls each respective rate based on target profile of said sensed condition associated with each gate.

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20. An injection molding system comprising:  
an injection molding machine;  
a hot runner including a manifold and a plurality of injection nozzles for  
5 distributing material injected from said injection molding machine to a plurality of gates  
leading to one or more mold cavities;  
a controller to individually control respective rates at which material is injected  
through said gates during an injection cycle; and  
at least one pressure transducer mounted in the one or more cavities, the pressure  
10 transducer coupled to the controller to send pressure data to the controller, wherein the  
controller alters the at least one respective rate from an injection pressure to a pack  
pressure when the pressure transducer detects a predetermined pressure value.

21. The injection molding system of claim 20, wherein control of each rate is  
15 based on a sensed condition related to the rate of material flow through each gate, each  
sensed condition being sensed at location in said hot runner.

22. The injection molding system of claim 20, wherein the at least one  
pressure transducer is a plurality of pressure transducers each respectively associated  
20 with one of said plurality of gates.

23. The injection molding system of claim 22, wherein each pressure  
transducer is located adjacent to the gate associated therewith.

24. The injection molding system of claim 22, wherein said one or more  
25 cavities is a plurality of cavities, and each pressure transducer is located adjacent an end  
of one of said plurality of cavities.

25. The injection molding system of claim 21, further comprising a plurality  
30 of pressure transducers coupled to said hot runner for sensing said sensed conditions,  
each pressure transducer being associated with one of said gates.

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26. The injection molding system of claim 25, wherein each pressure transducer is coupled to one of said plurality of injection nozzles.

27. The injection molding system of claim 25, wherein each pressure  
5 transducer is coupled to the manifold.

28. An injection molding system comprising:  
an injection molding machine;  
a hot runner including a manifold and a plurality of injection nozzles for  
10 distributing material injected from said injection molding machine to a plurality of gates  
leading to one or more mold cavities;  
a controller to individually control respective rates at which material is injected  
through said gates during an injection cycle; and  
at least one pressure transducer mounted in the one or more cavities, the pressure  
15 transducer coupled to the controller to send pressure data to the controller, wherein the  
controller determines an end of the pack period of the injection cycle for at least one  
respective rate when the pressure transducer detects a predetermined pressure value.

29. The injection molding system of claim 28, wherein the at least one  
20 pressure transducer is a plurality of pressure transducers each respectively associated  
with one of said plurality of gates.

30. The injection molding system of claim 29, wherein said one or more  
cavities is a plurality of cavities, and each pressure transducer is located adjacent an end  
25 of one of said plurality of cavities.

31. An injection molding system comprising:  
an injection molding machine;  
a hot runner including a manifold and a plurality of injection nozzles for  
30 distributing material injected from said injection molding machine to a plurality of gates  
leading to one or more mold cavities;

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a plurality of pressure transducers coupled to said hot runner for sensing material pressure flowing to said gates; and

at least one pressure transducer mounted in the one or more cavities, the pressure transducer to sense the material pressure inside the one or more cavities.

5

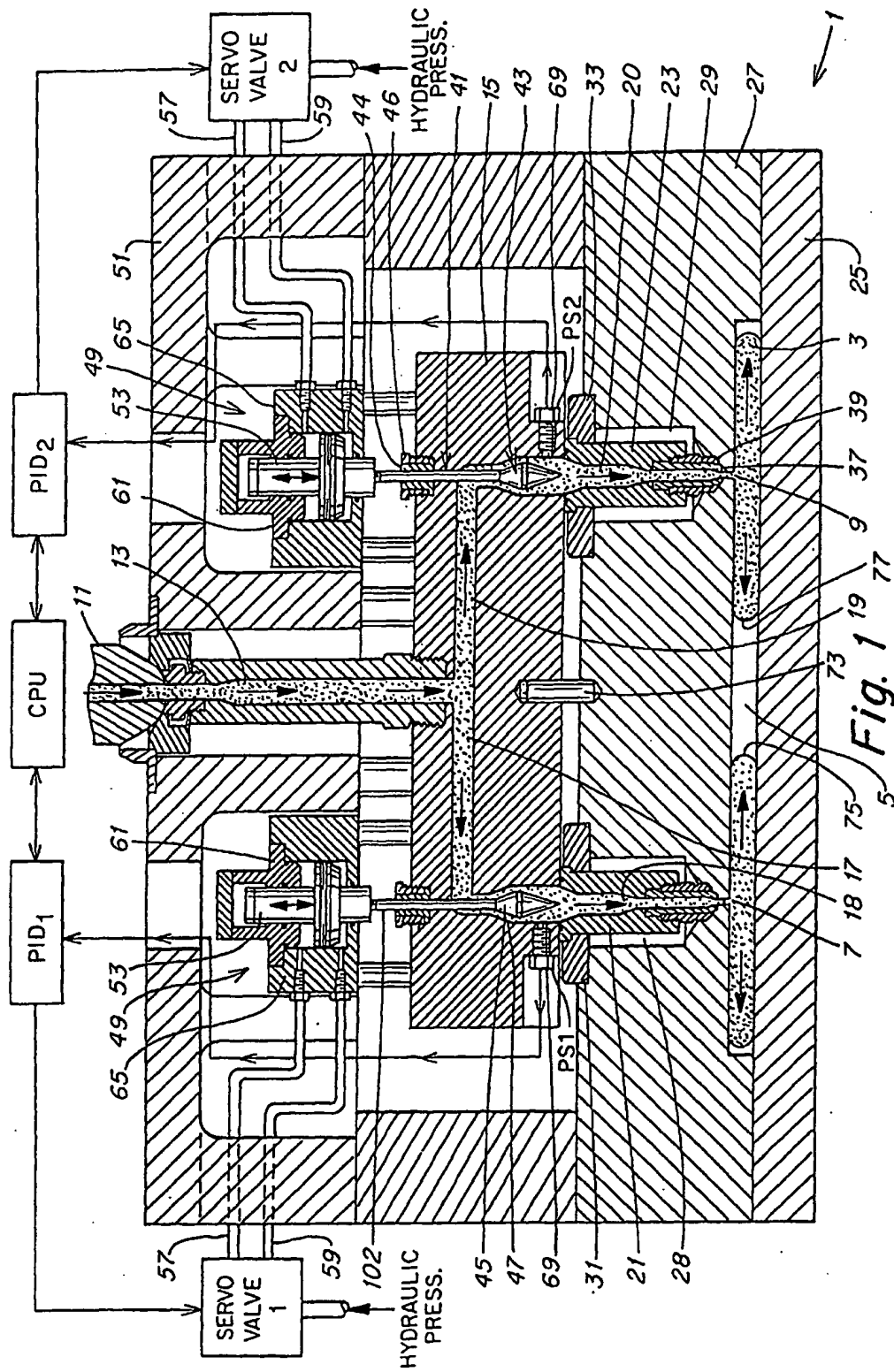
32. The injection molding system of claim 31, wherein each of said plurality of pressure transducers is coupled to one said plurality of injection nozzles.

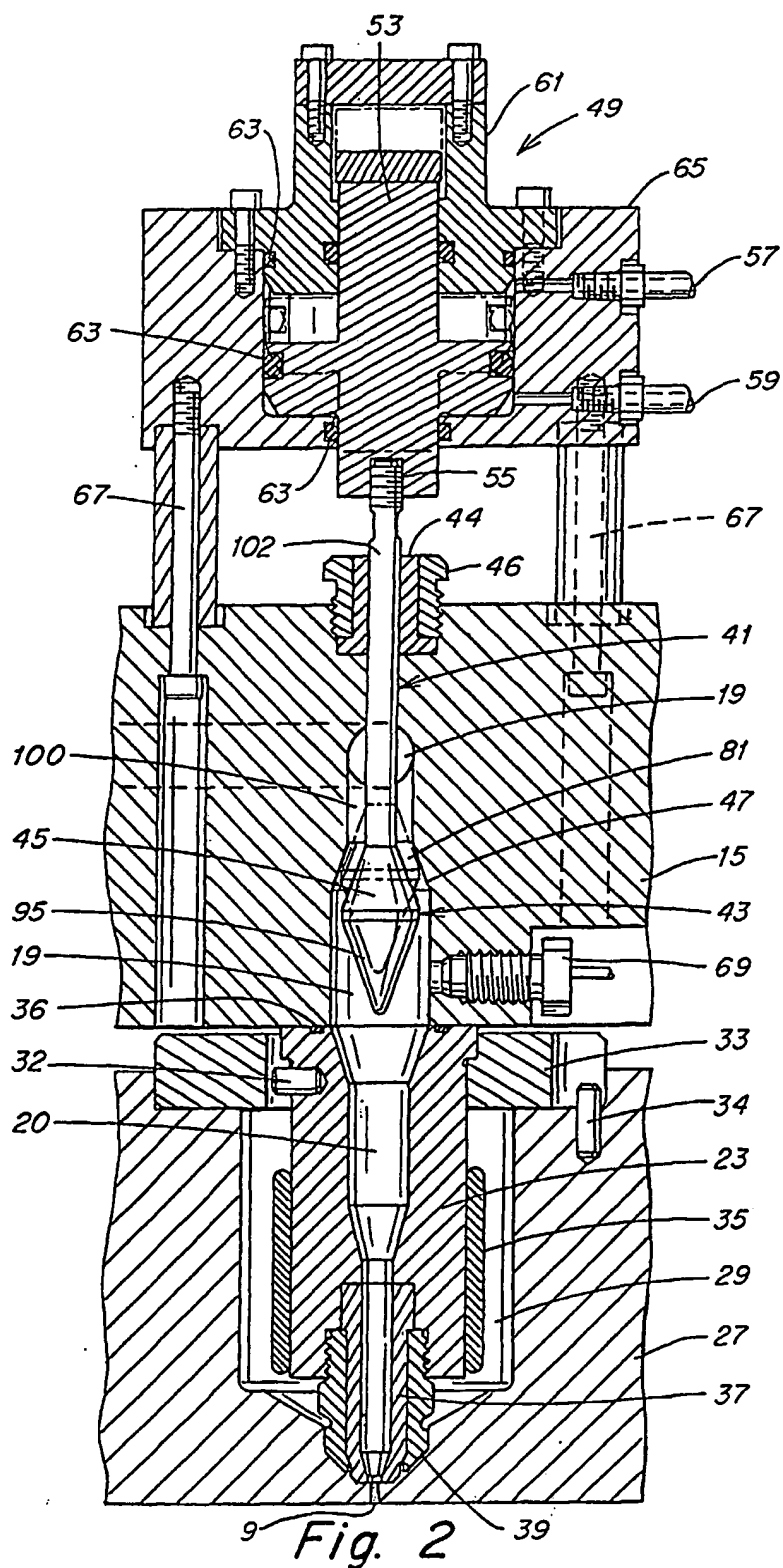
33. The injection molding system of claim 31, wherein each of said plurality  
10 of pressure transducers is coupled to a channel of the manifold leading to one of said gates.

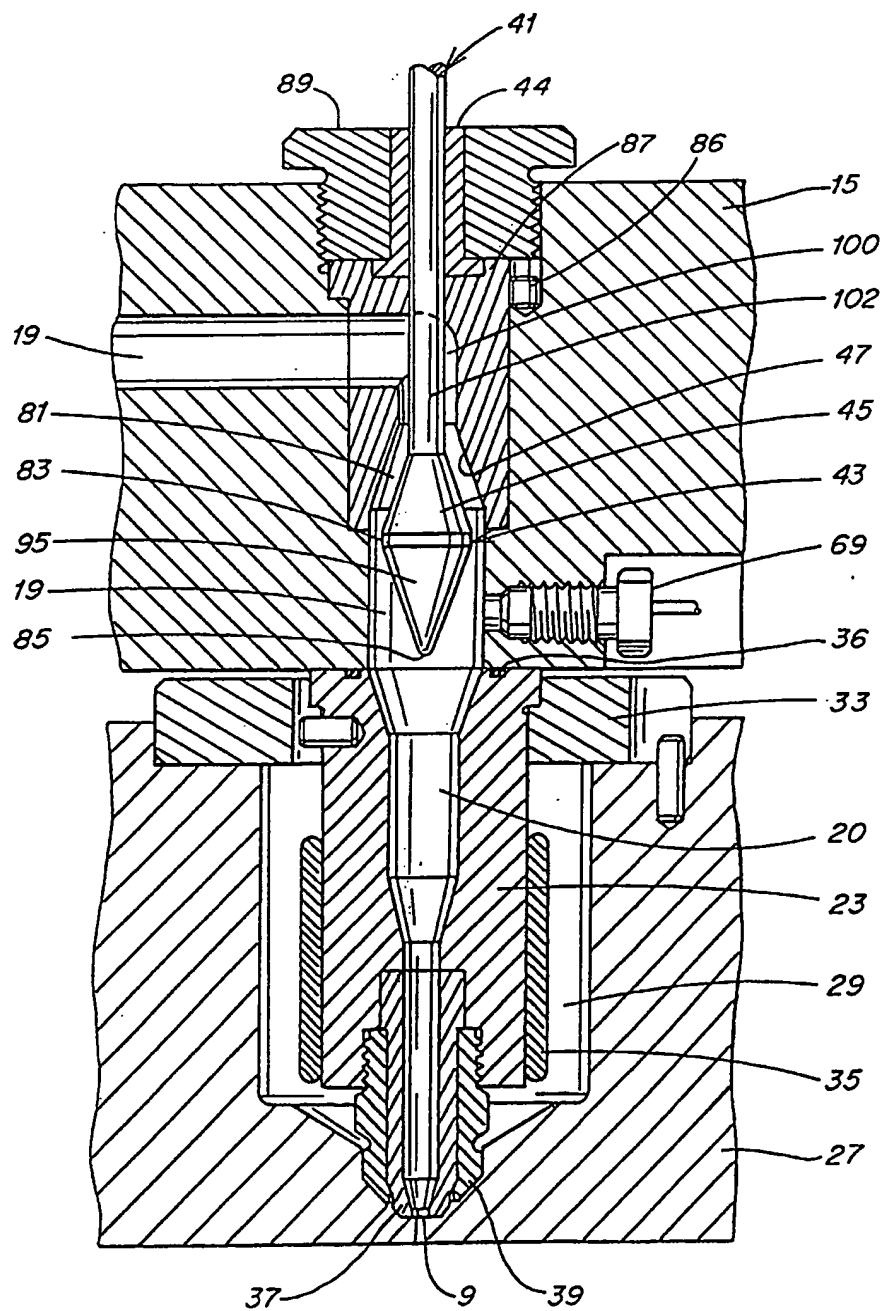
34. The injection molding system of claim 31, further comprising a controller  
to which the plurality of pressure transducers and the at least one pressure transducer are  
15 coupled, the controller controlling a rate of material flow through each gate based on pressure readings from the plurality of pressure transducers and the at least one pressure transducer.

20

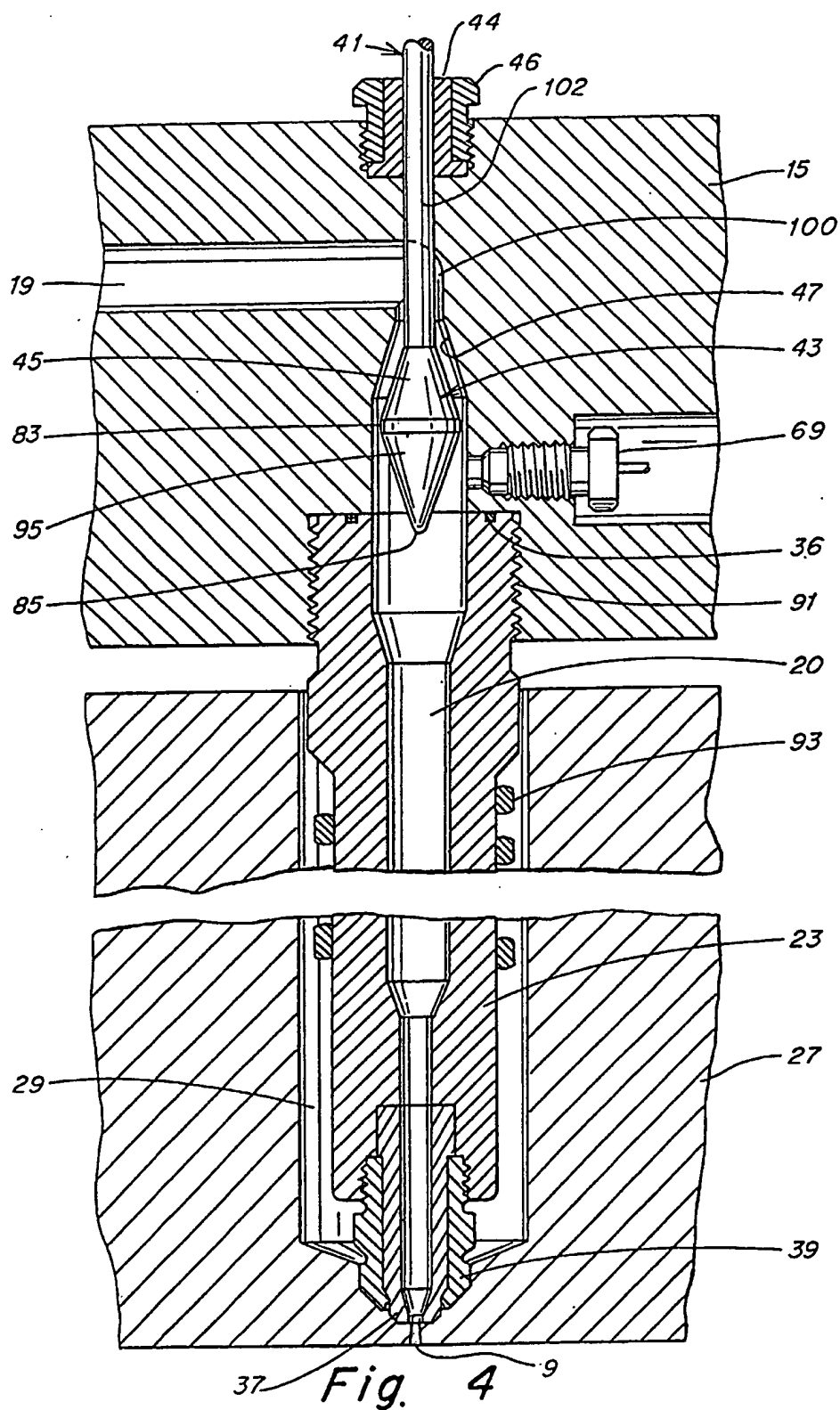


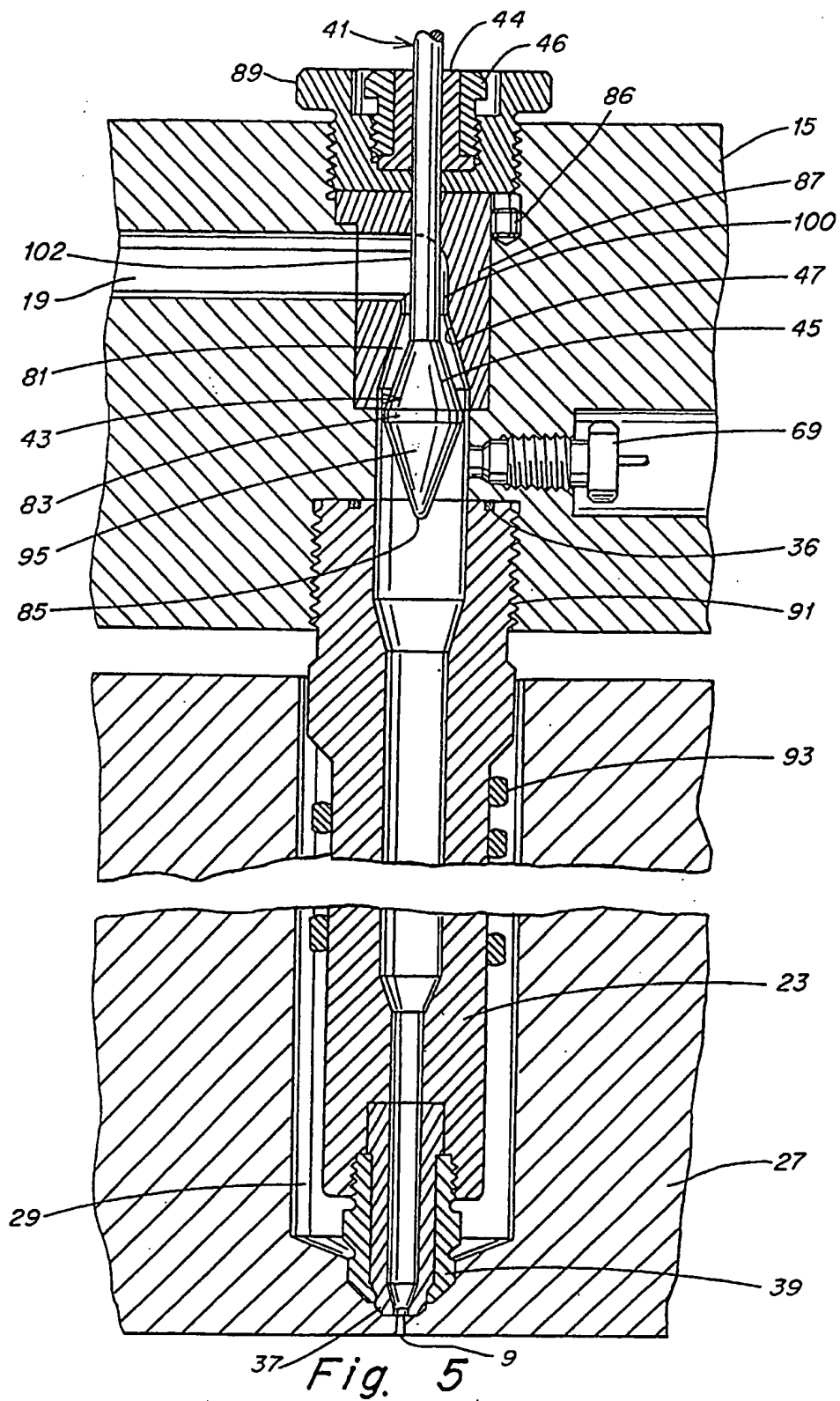


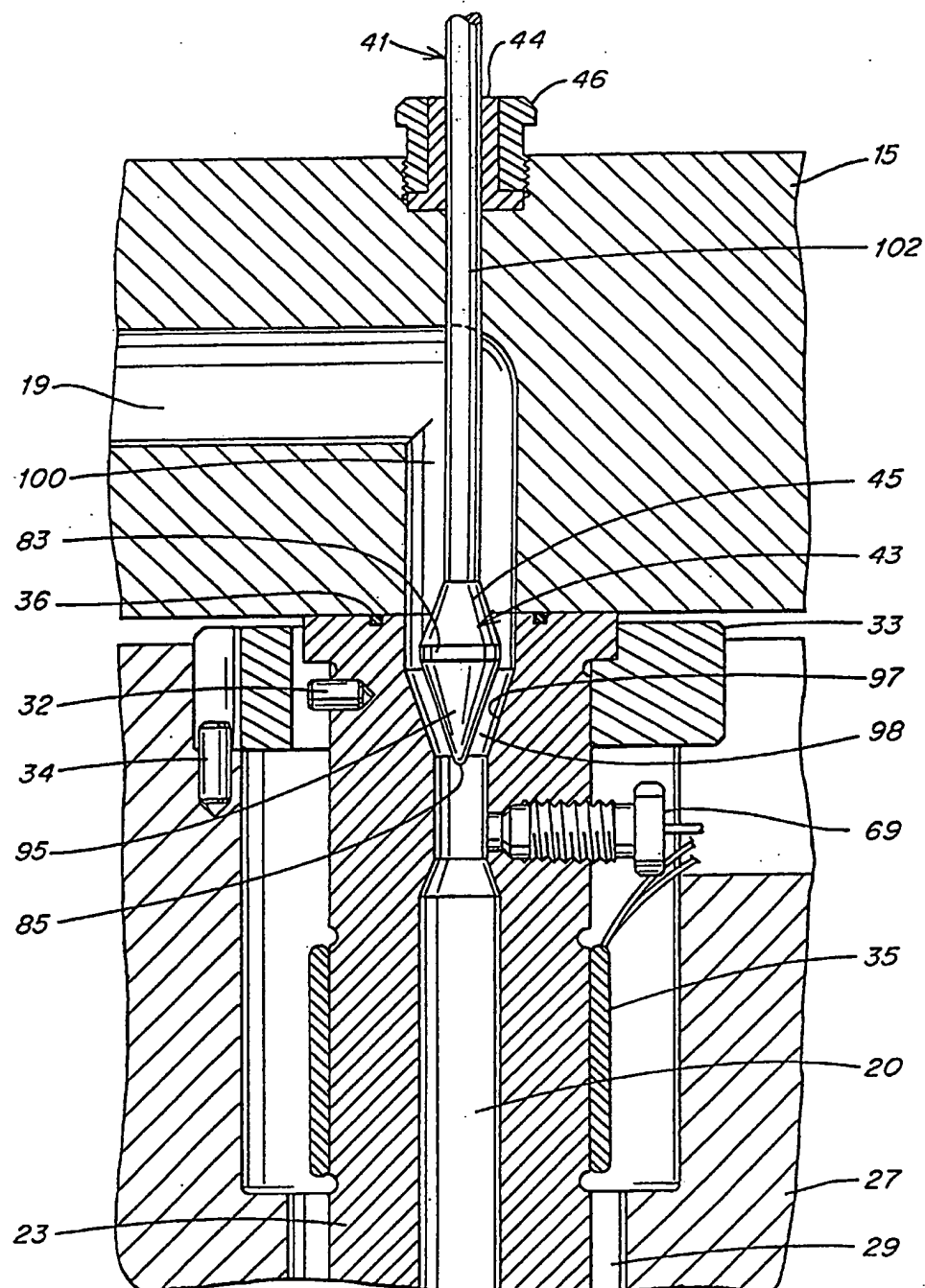


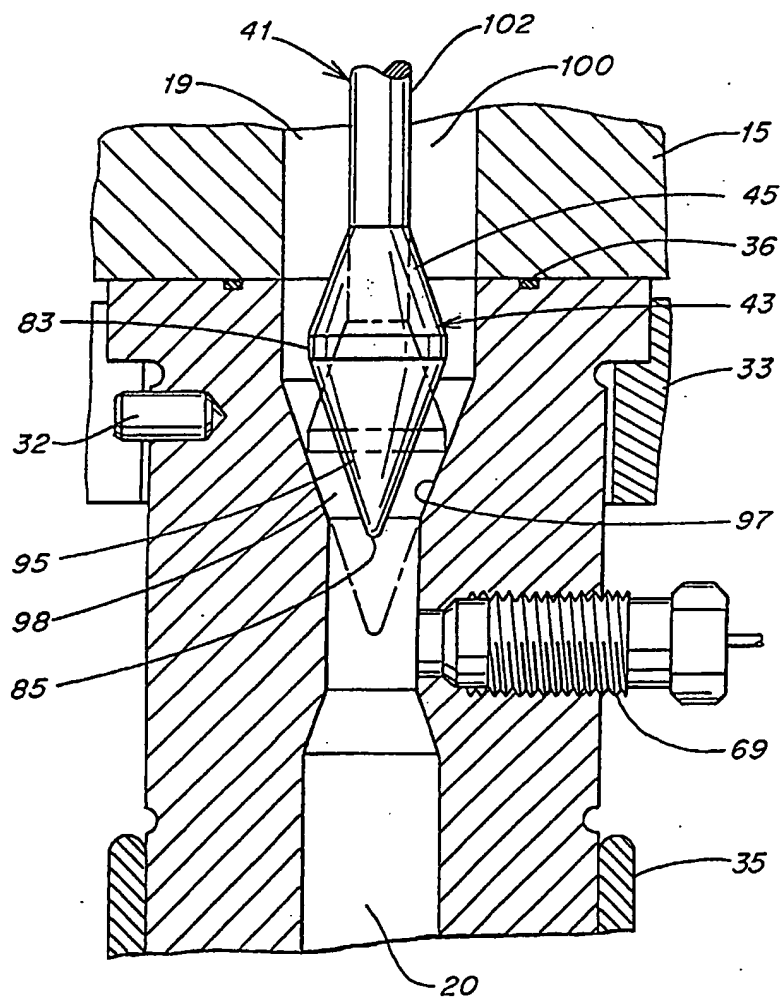


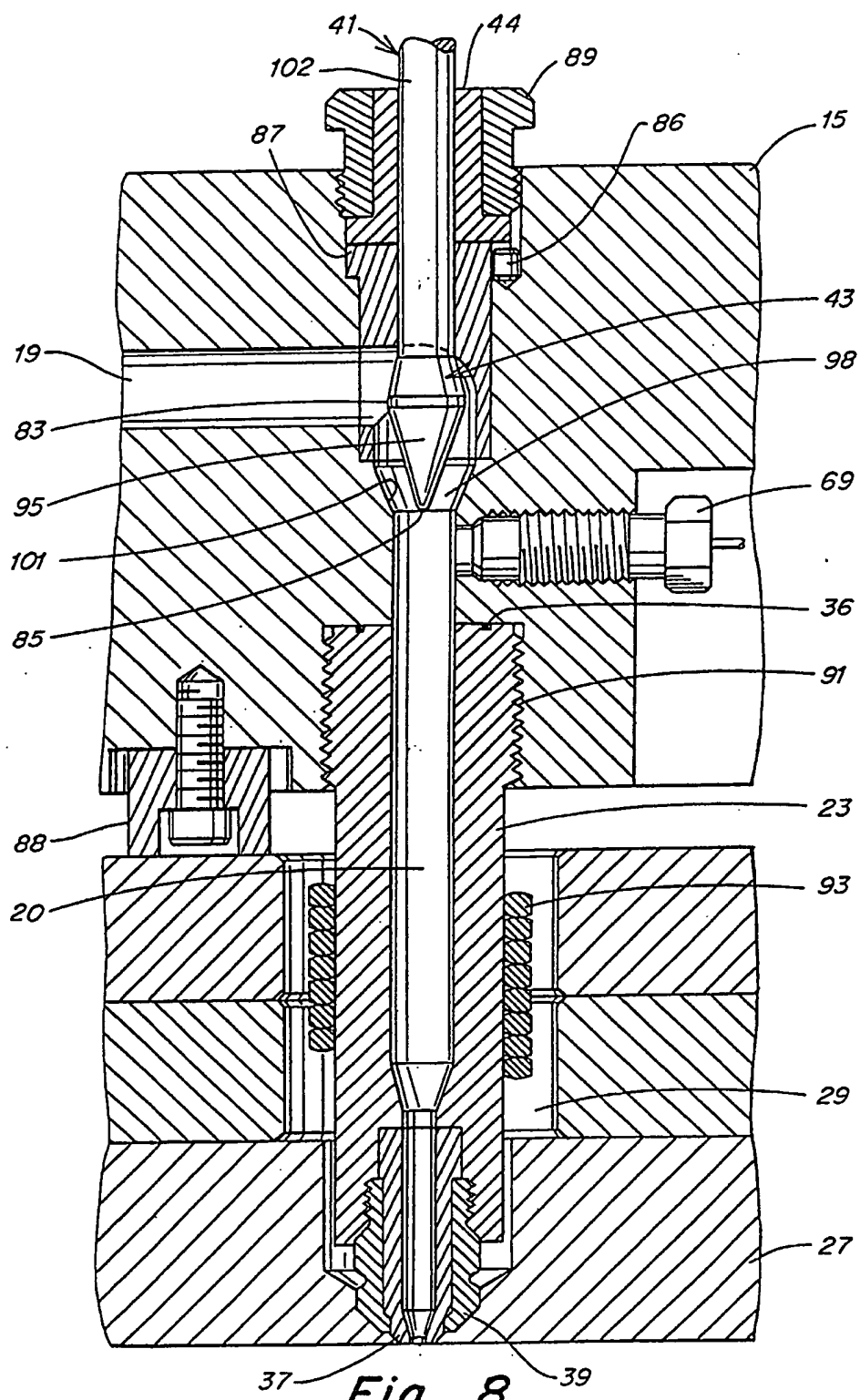
*Fig. 3*



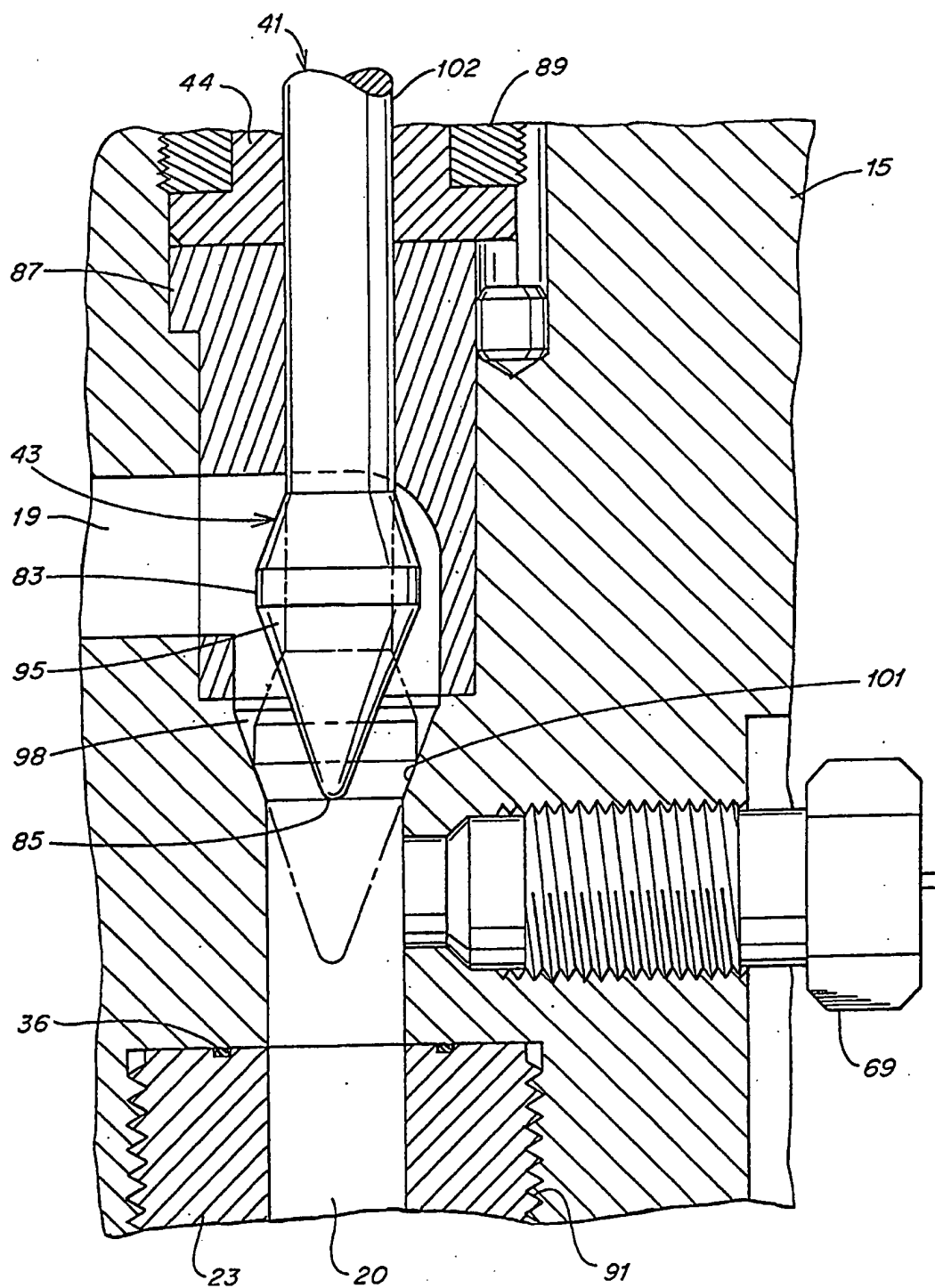


*Fig. 6*

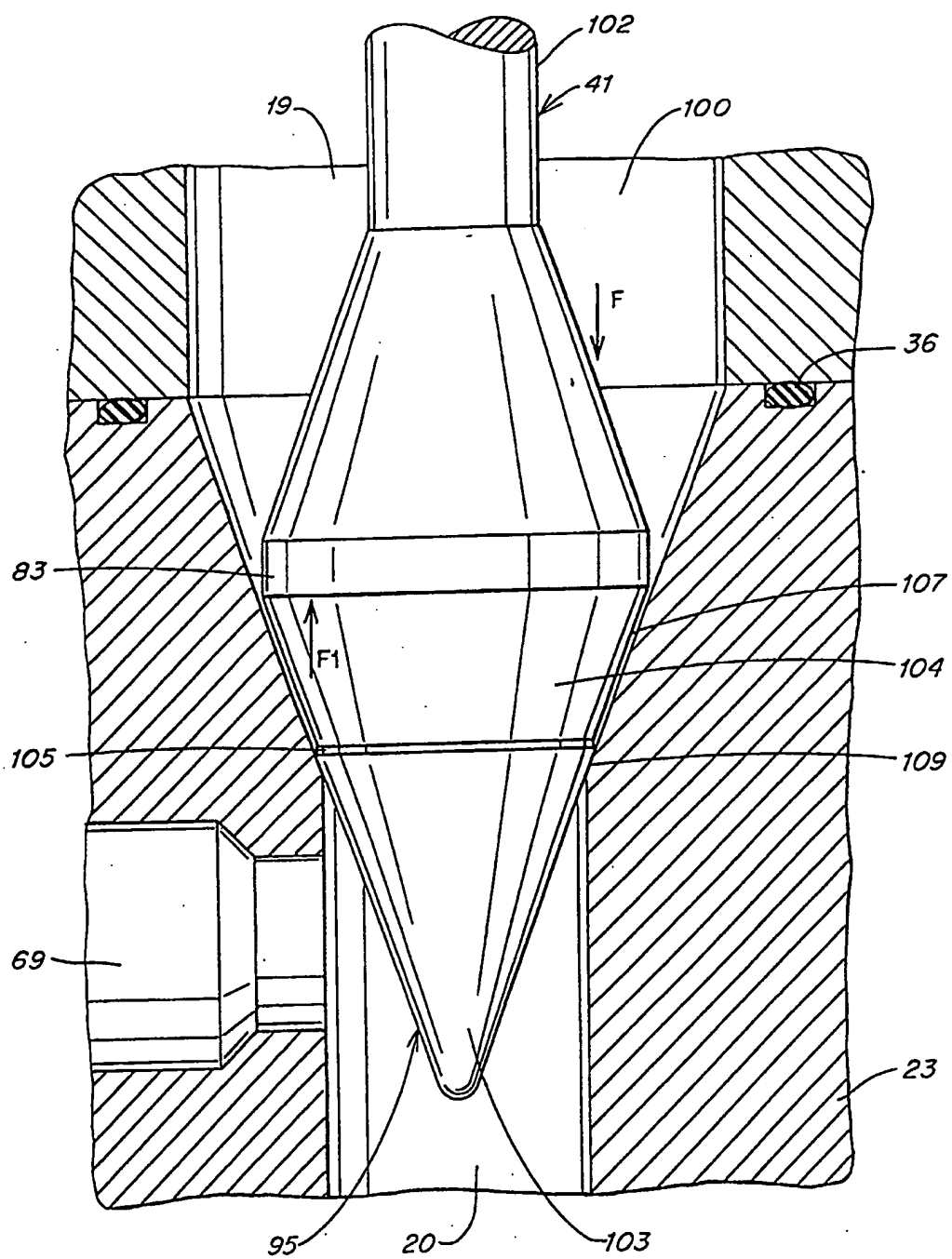
*Fig. 7*







*Fig. 9*

*Fig. 10*

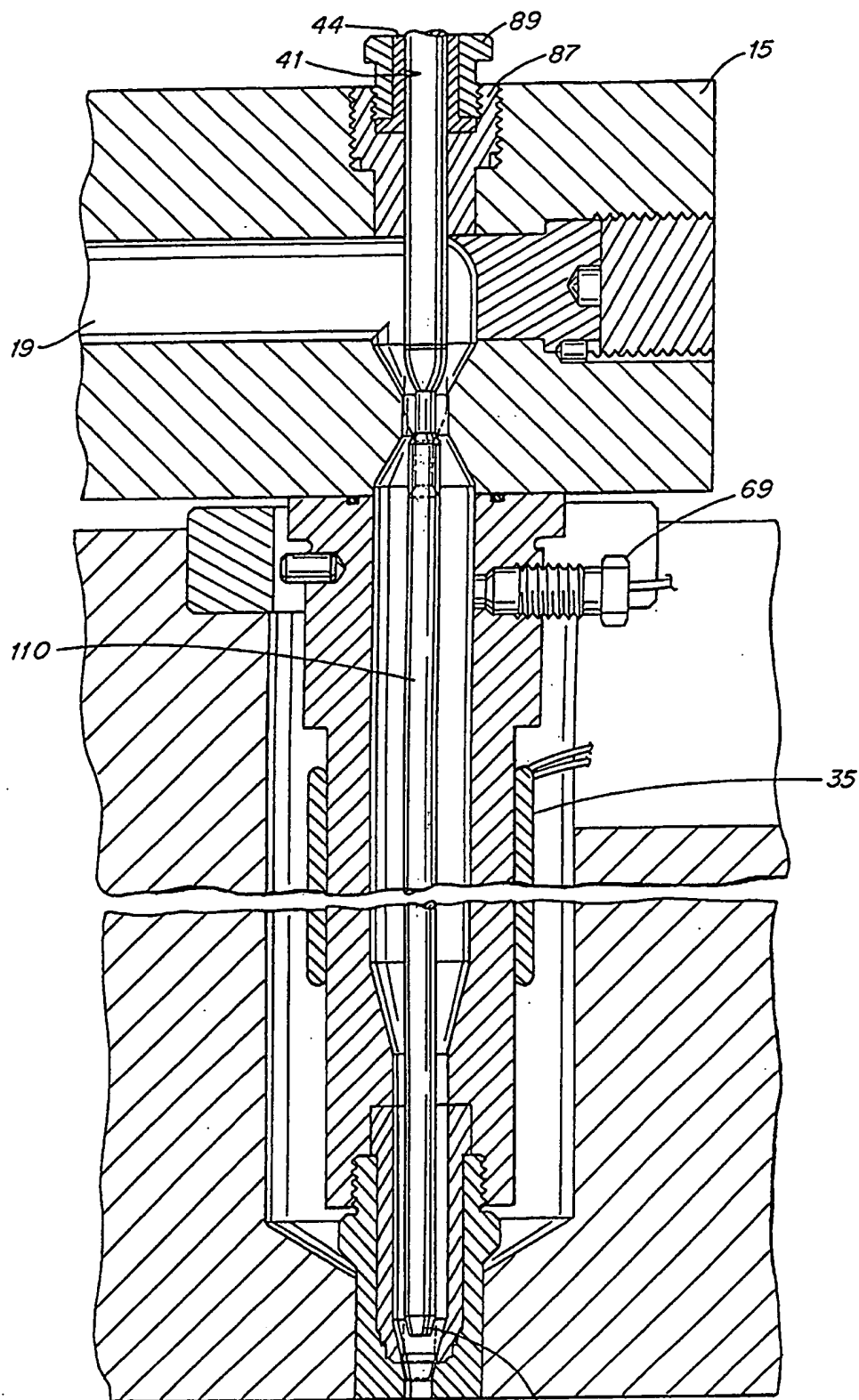
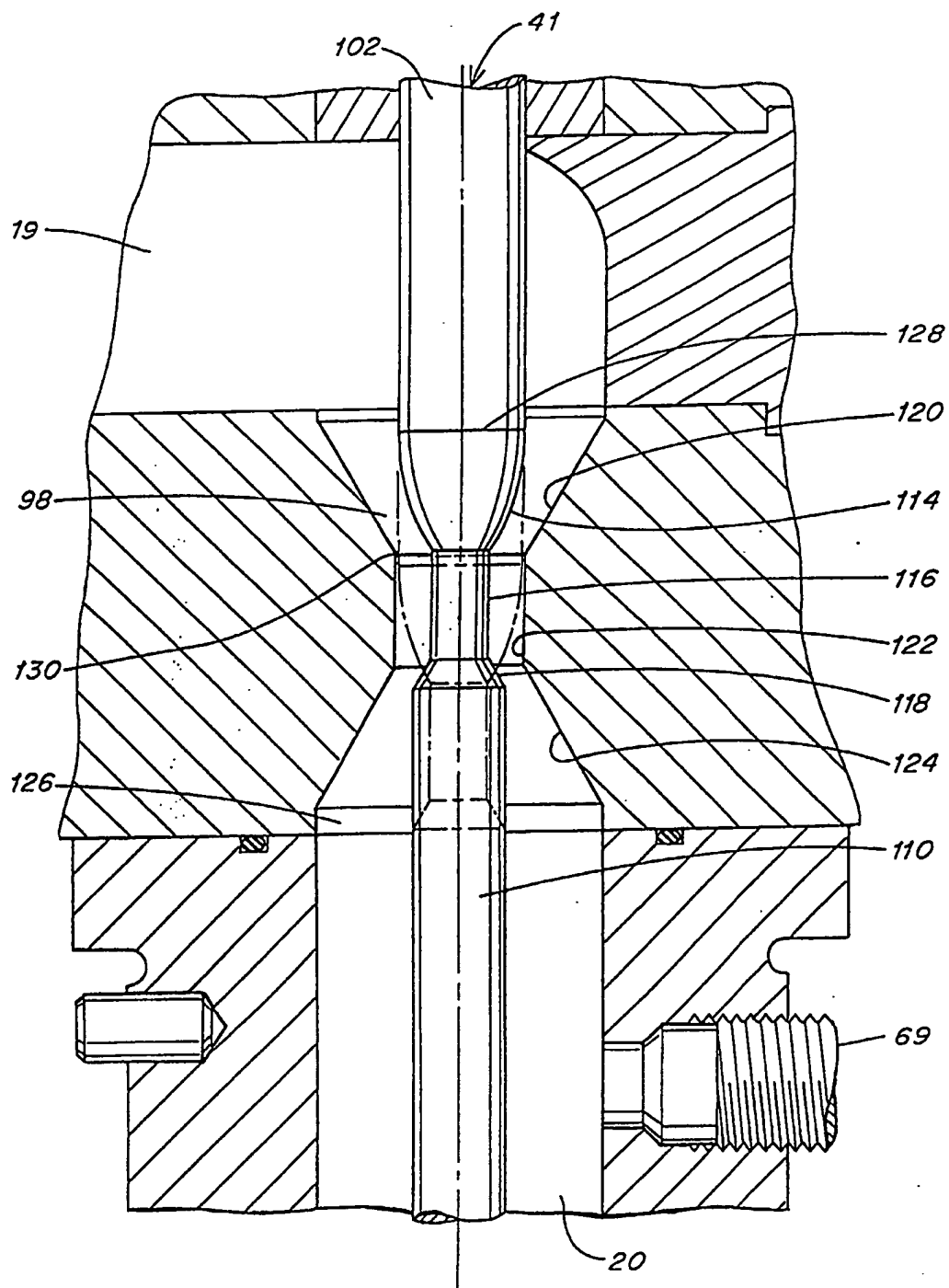
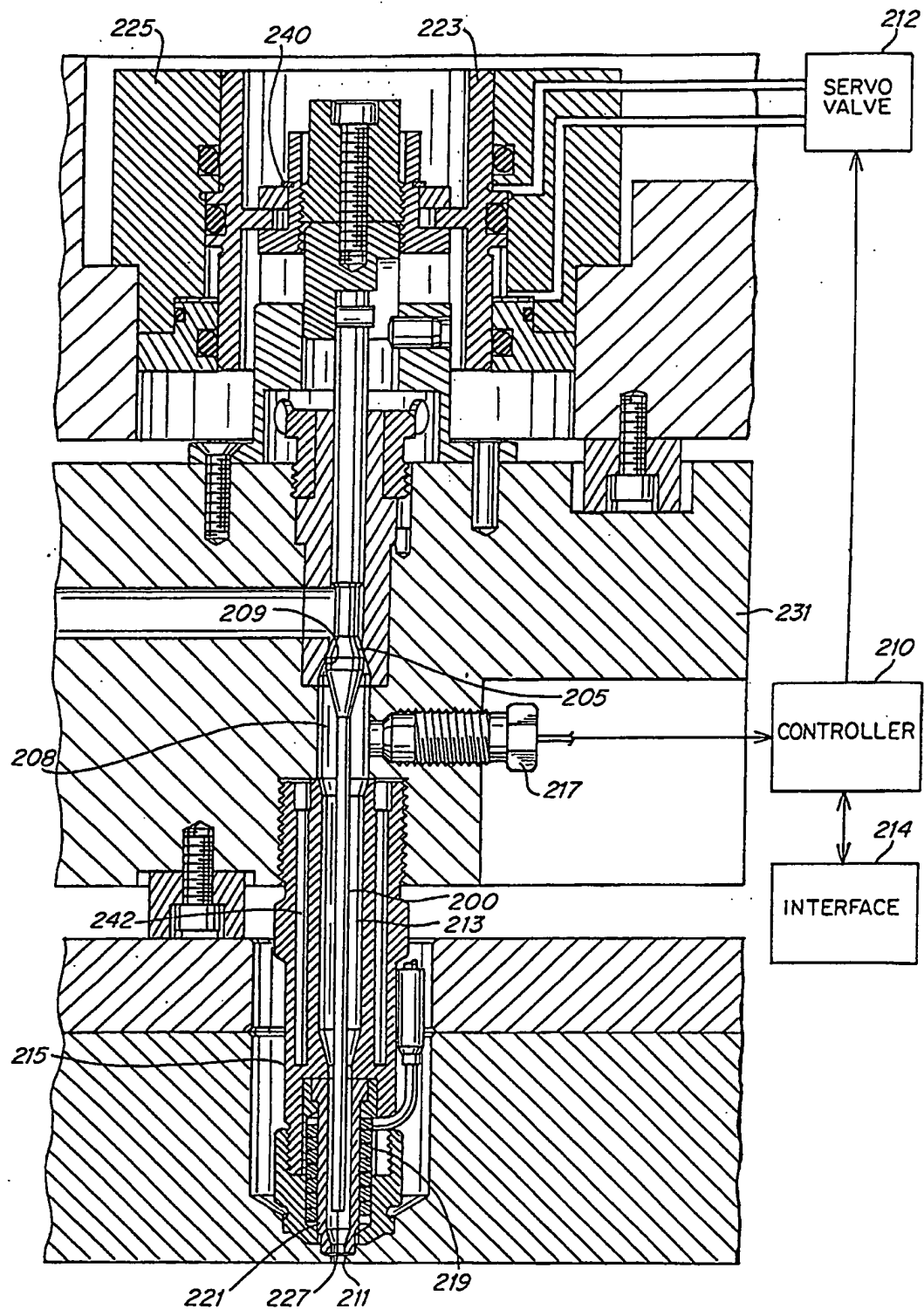


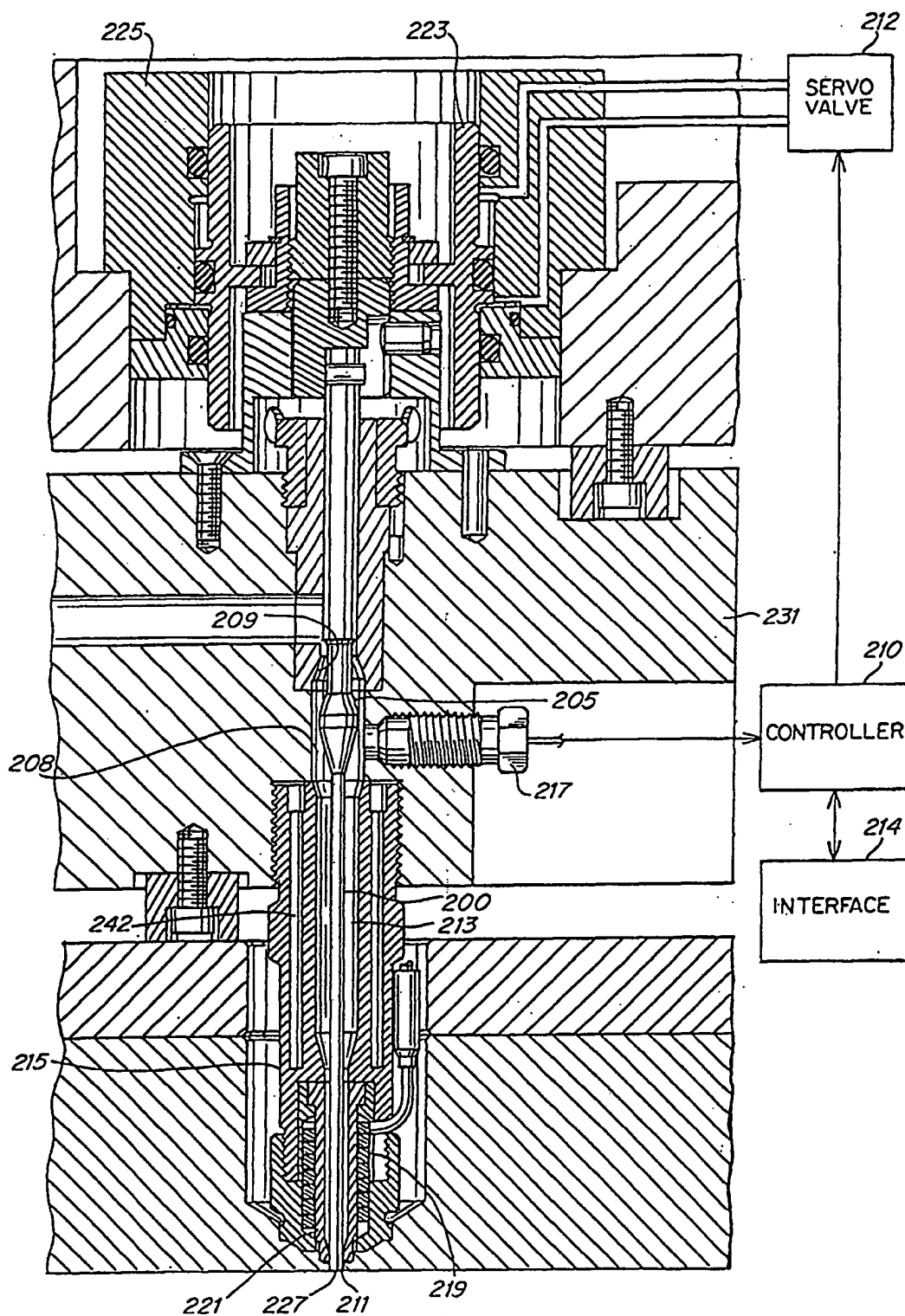
Fig. 11

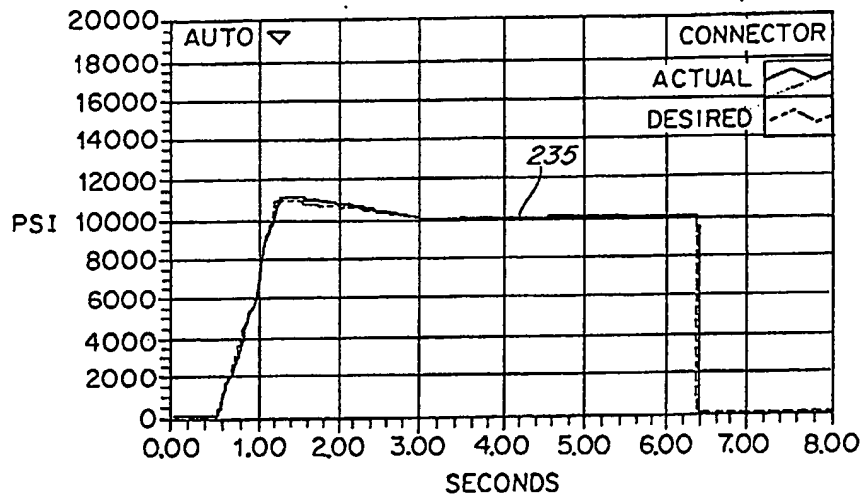
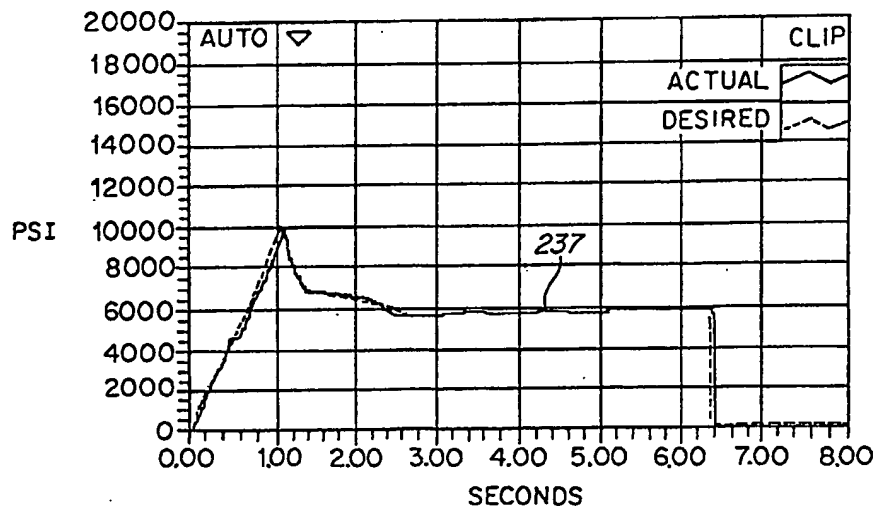
*Fig. 12*



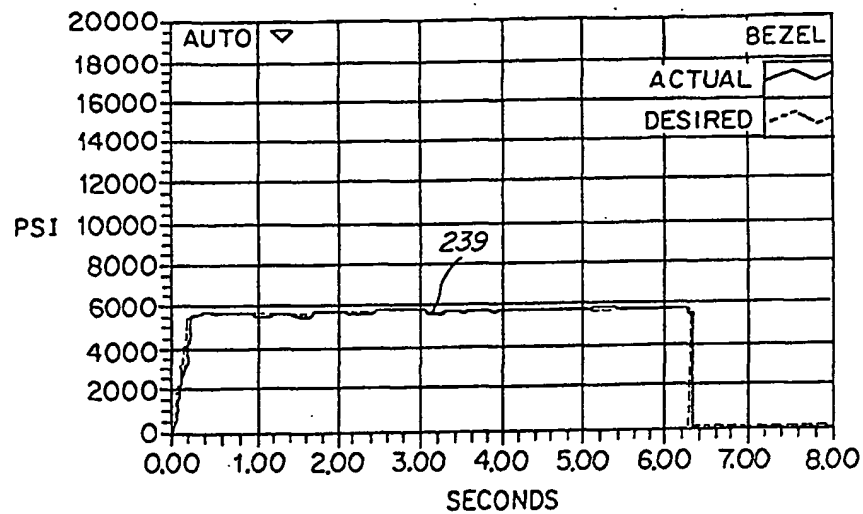
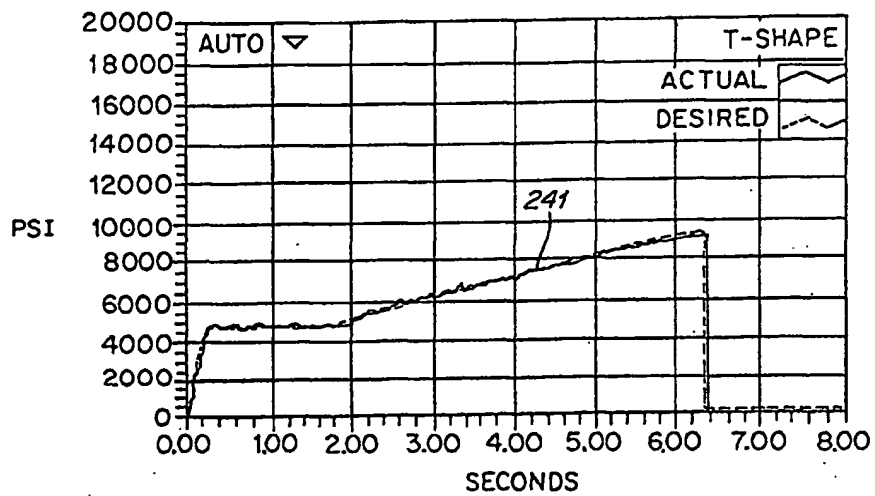
*Fig. 13*



*Fig. 15*

*Fig. 16a**Fig. 16b*



*Fig. 16c**Fig. 16d*

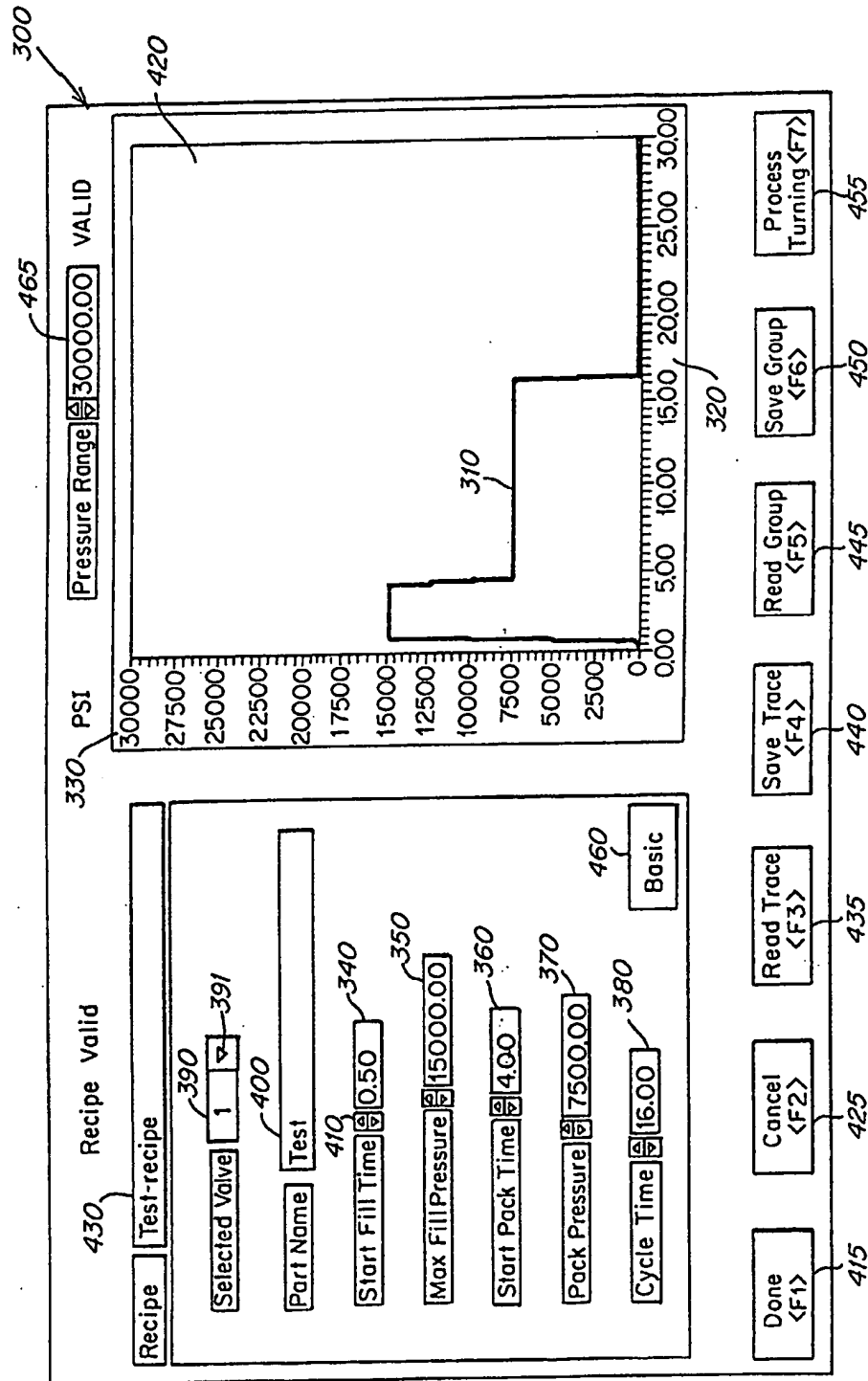


Fig. 17

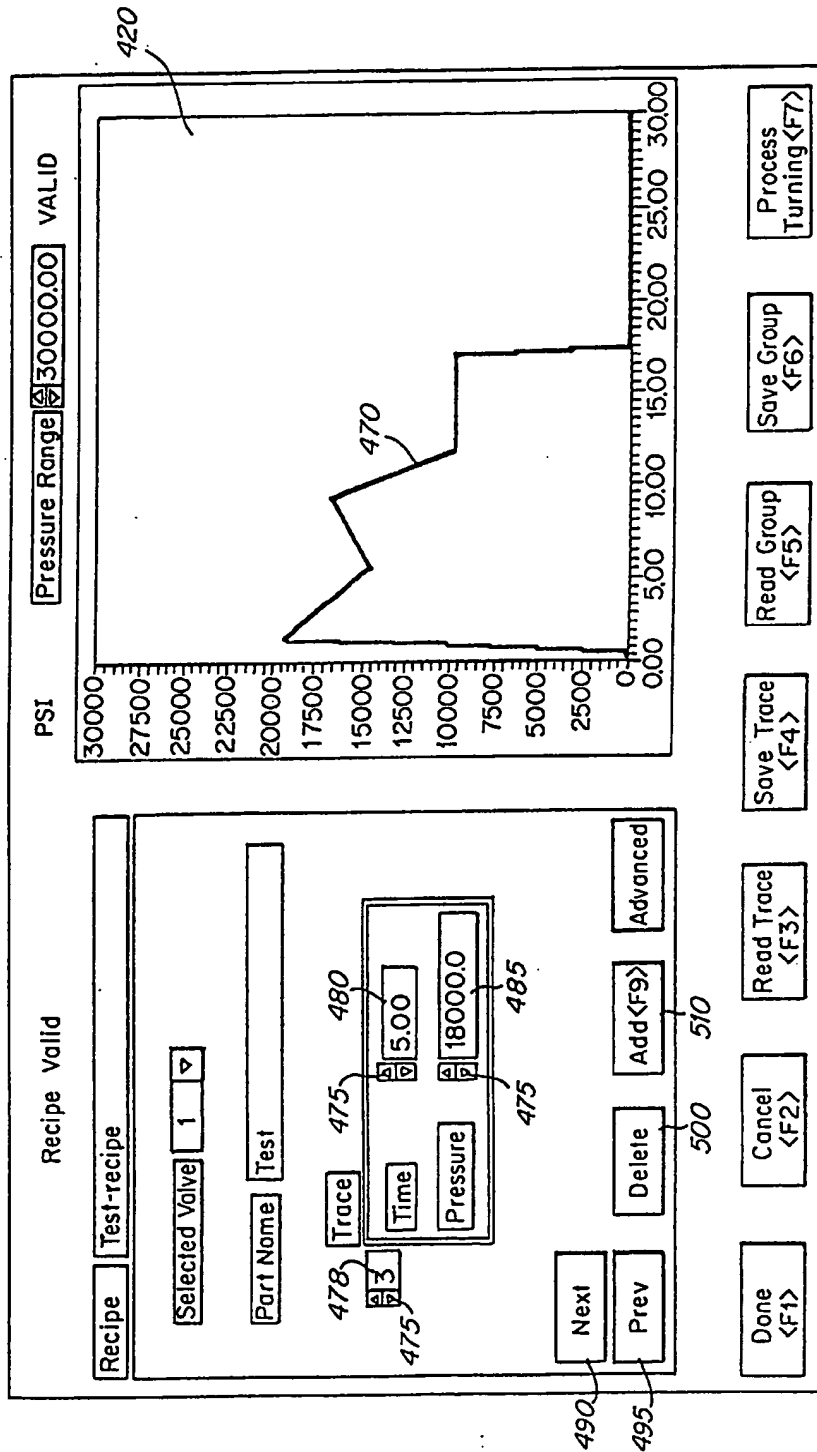
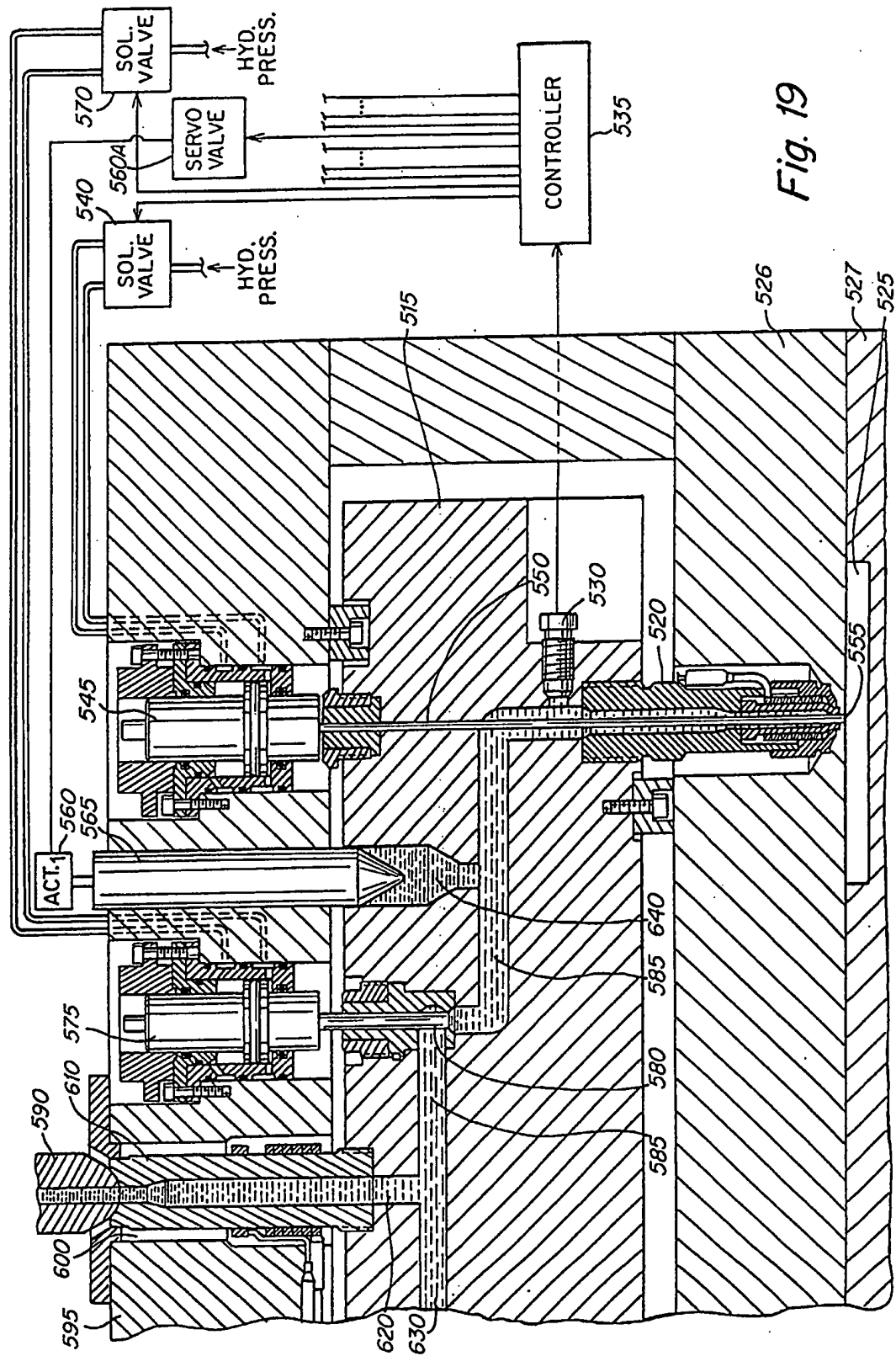
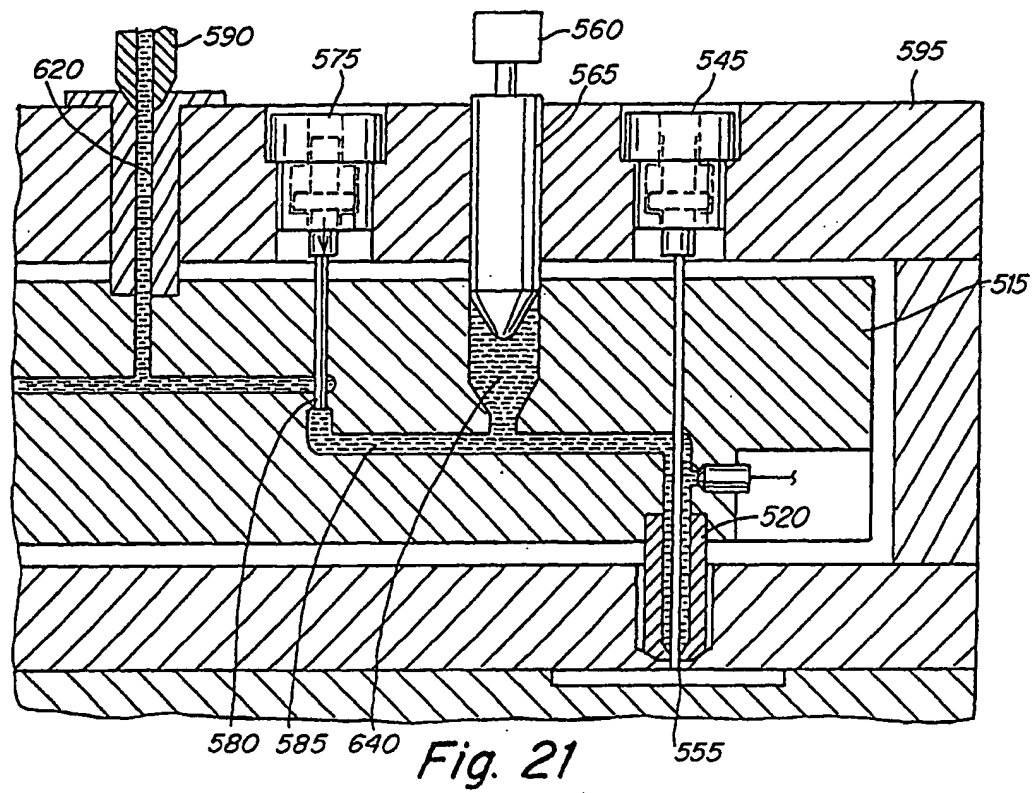
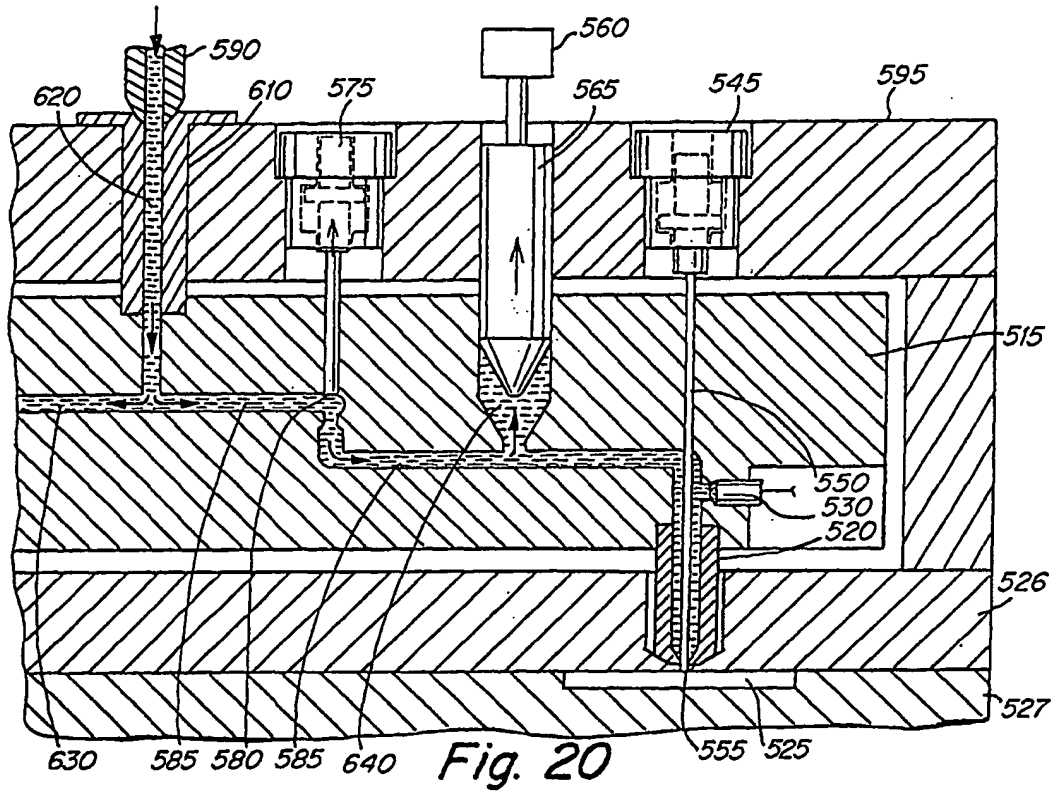
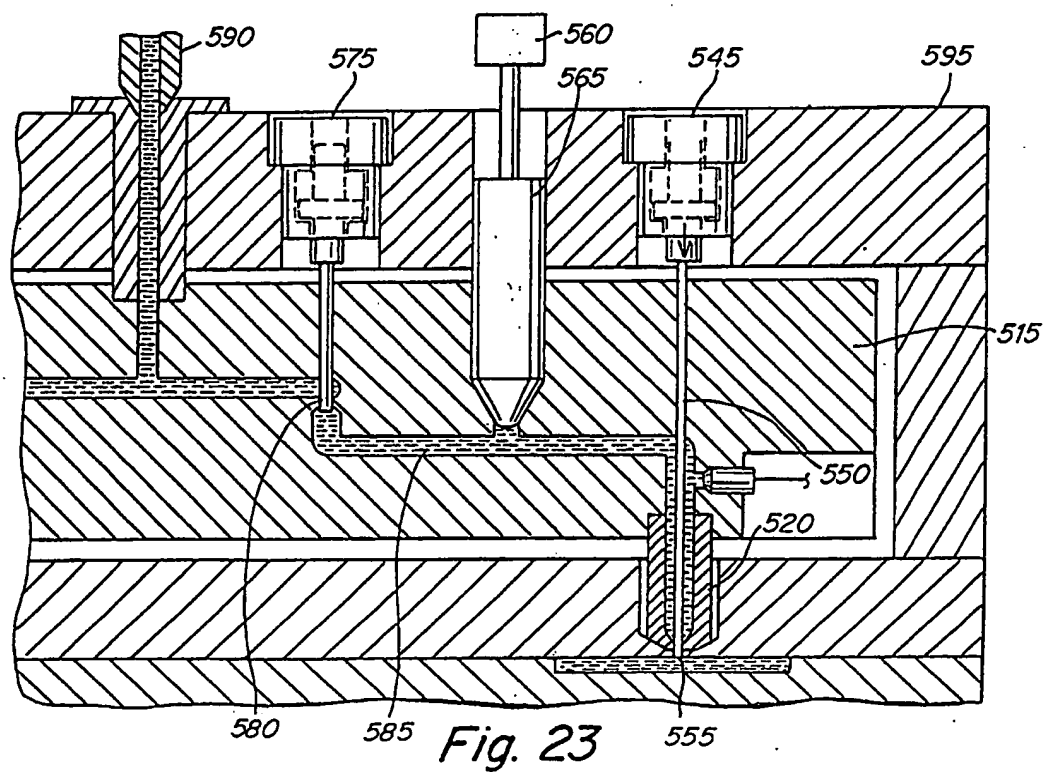
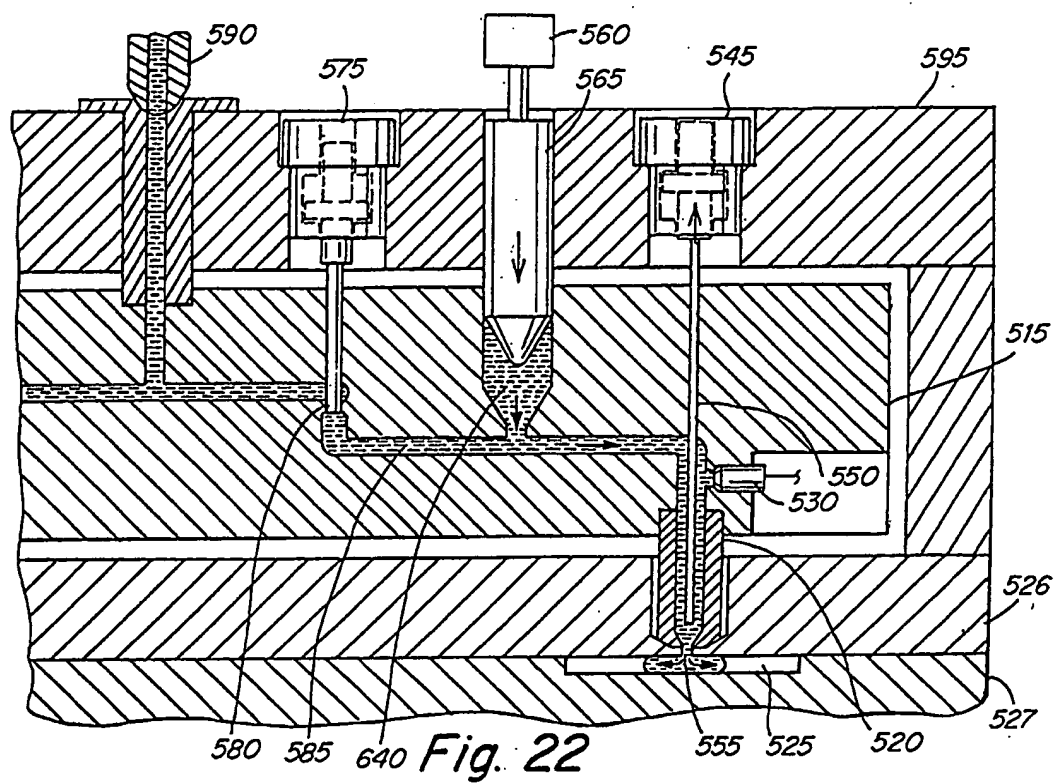


Fig. 18







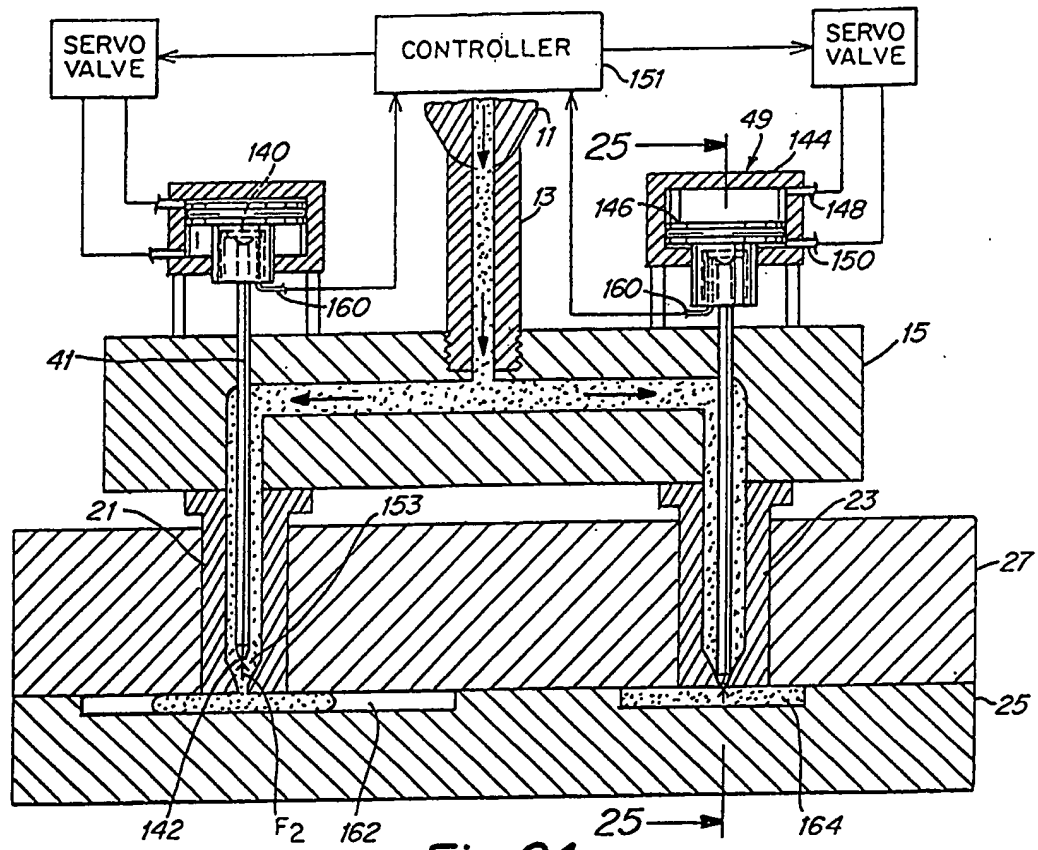


Fig. 24

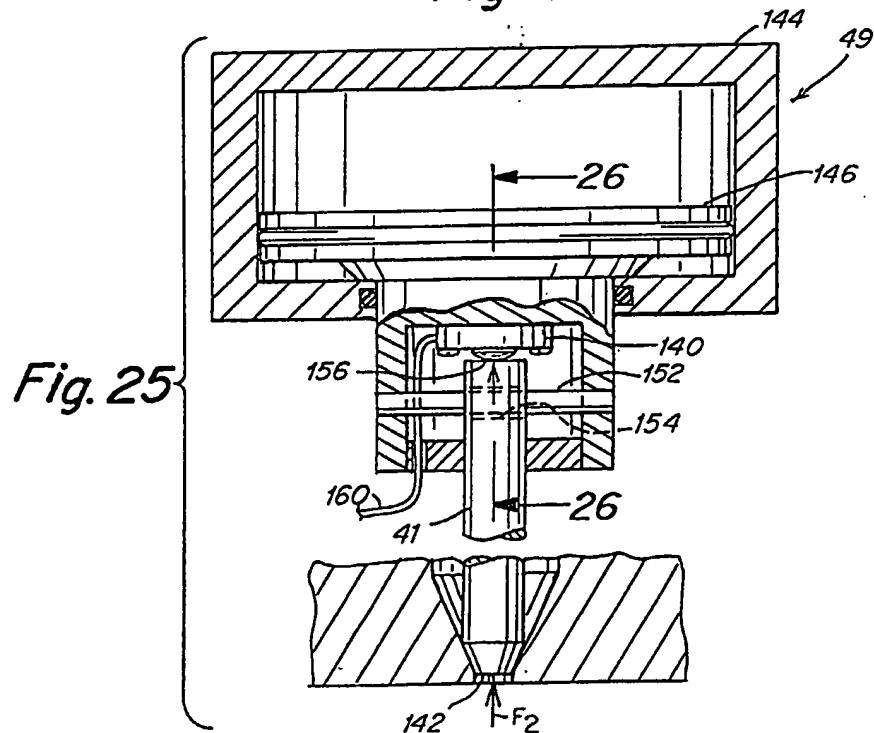
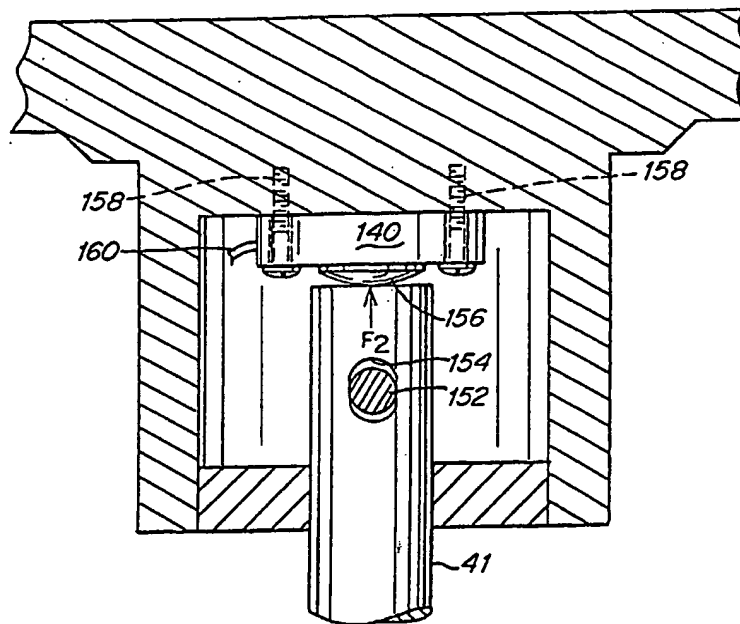
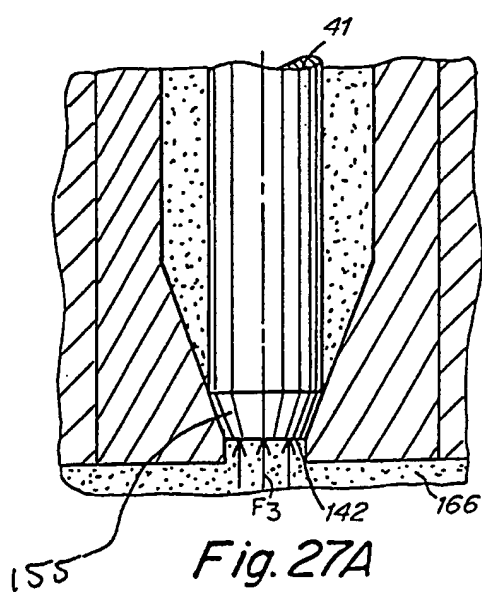
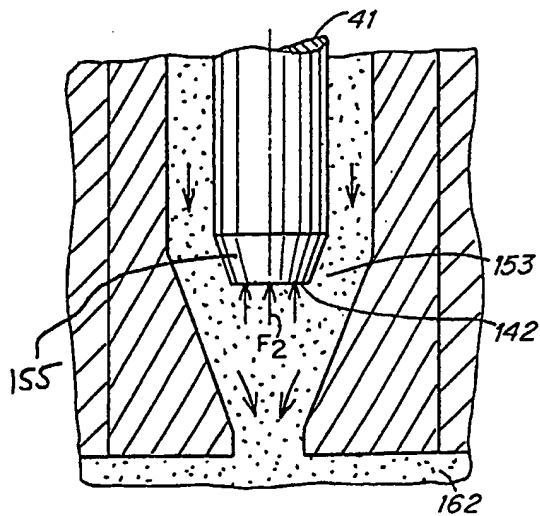
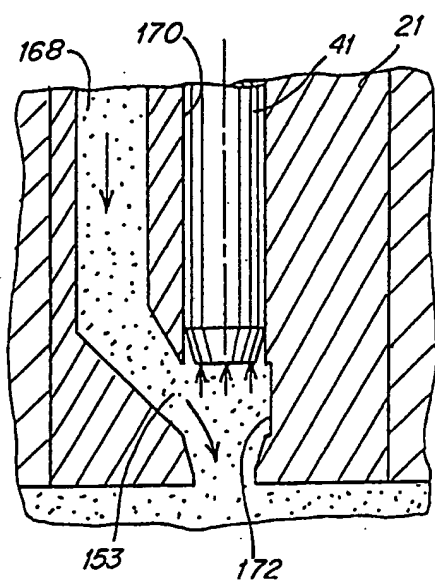
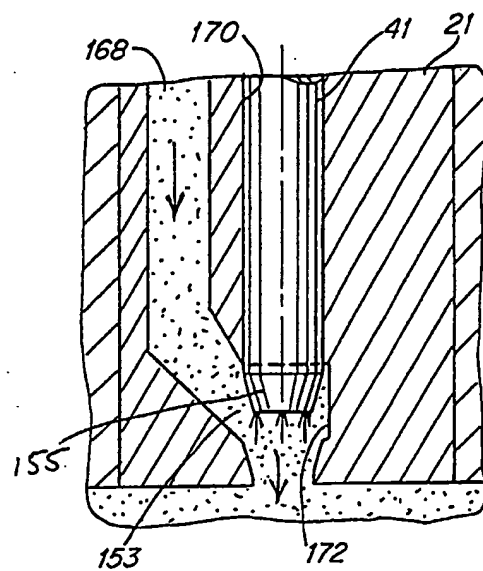
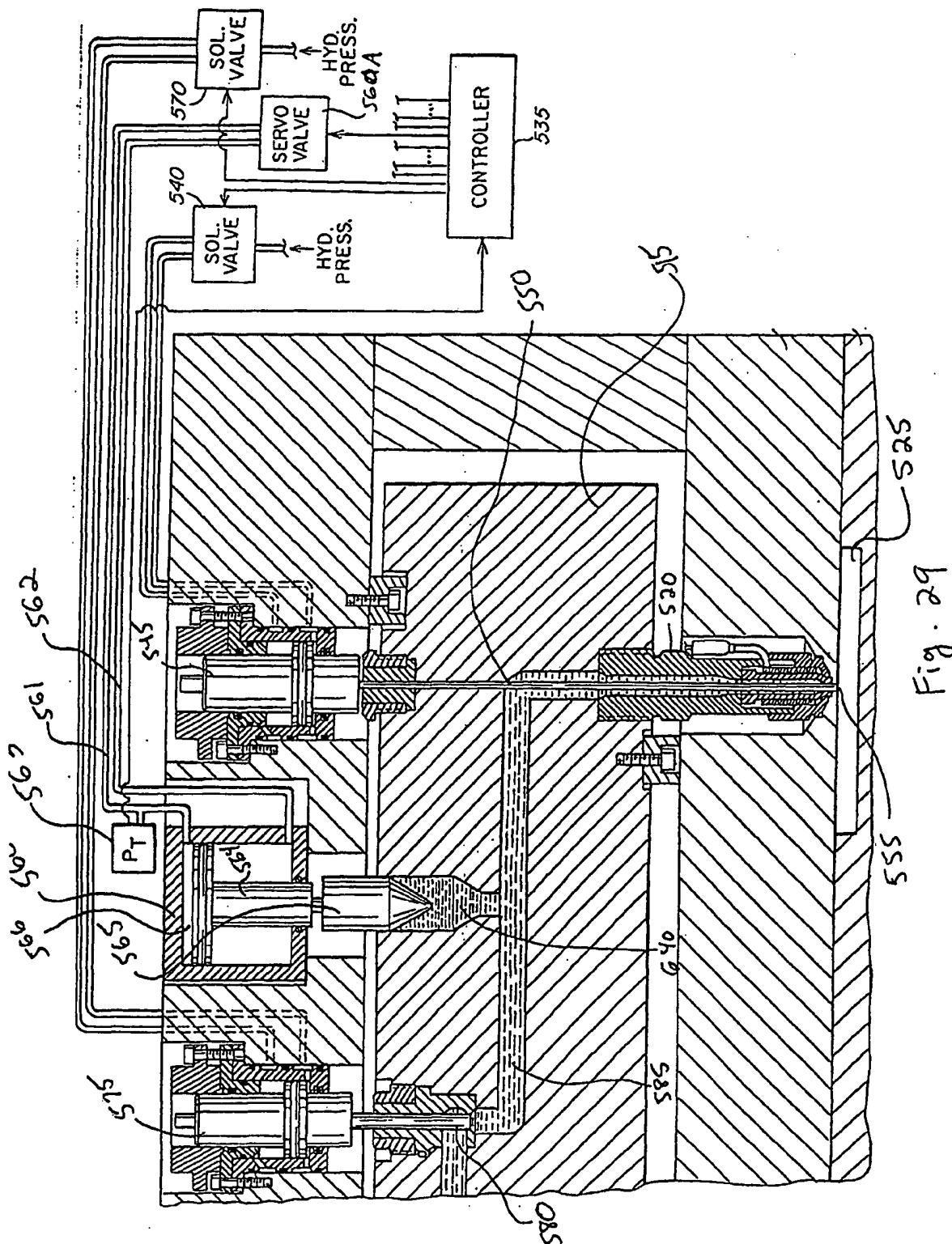


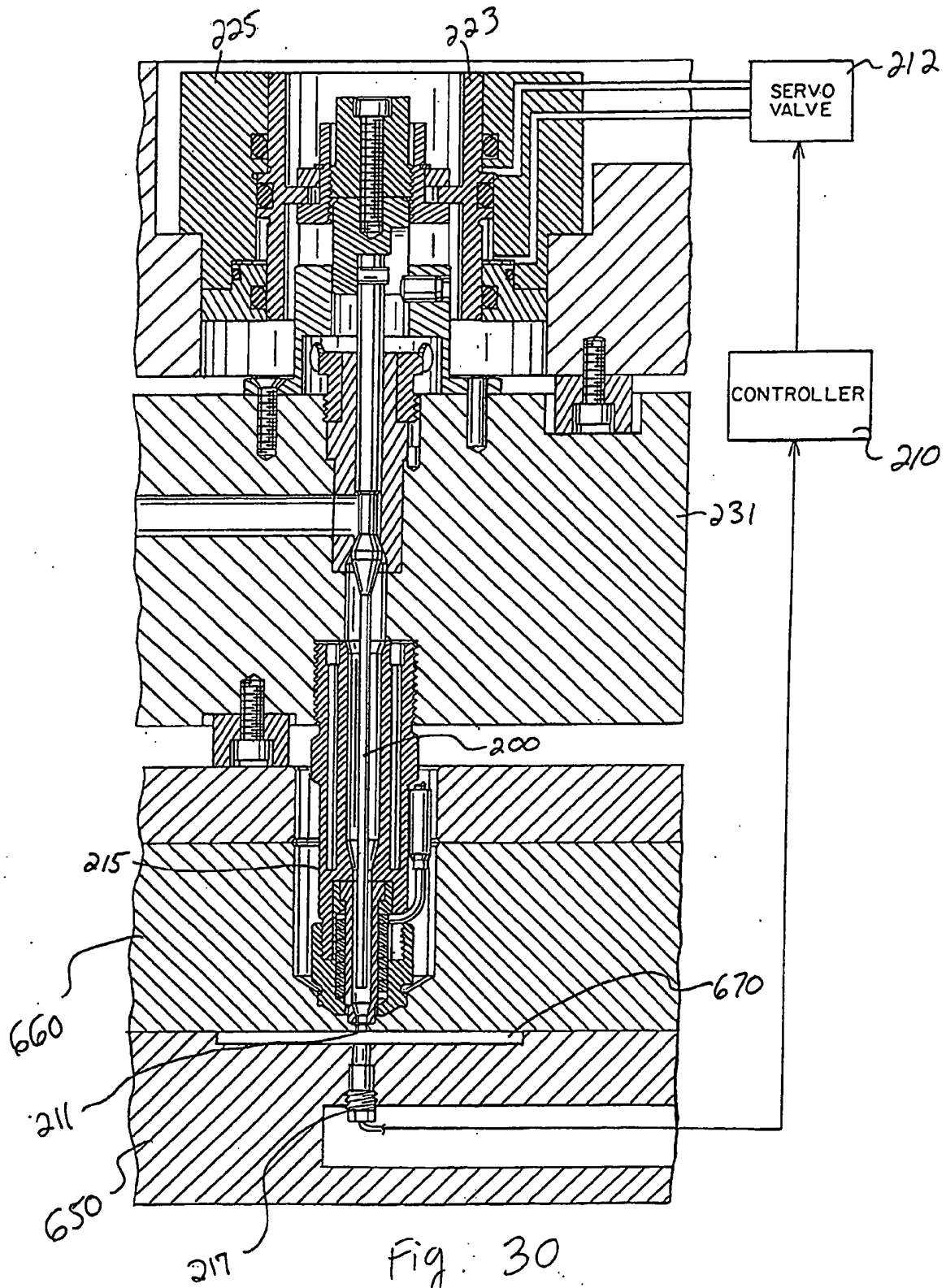
Fig. 25

*Fig. 26**Fig. 27A**Fig. 27B*



*Fig. 28A**Fig. 28B*





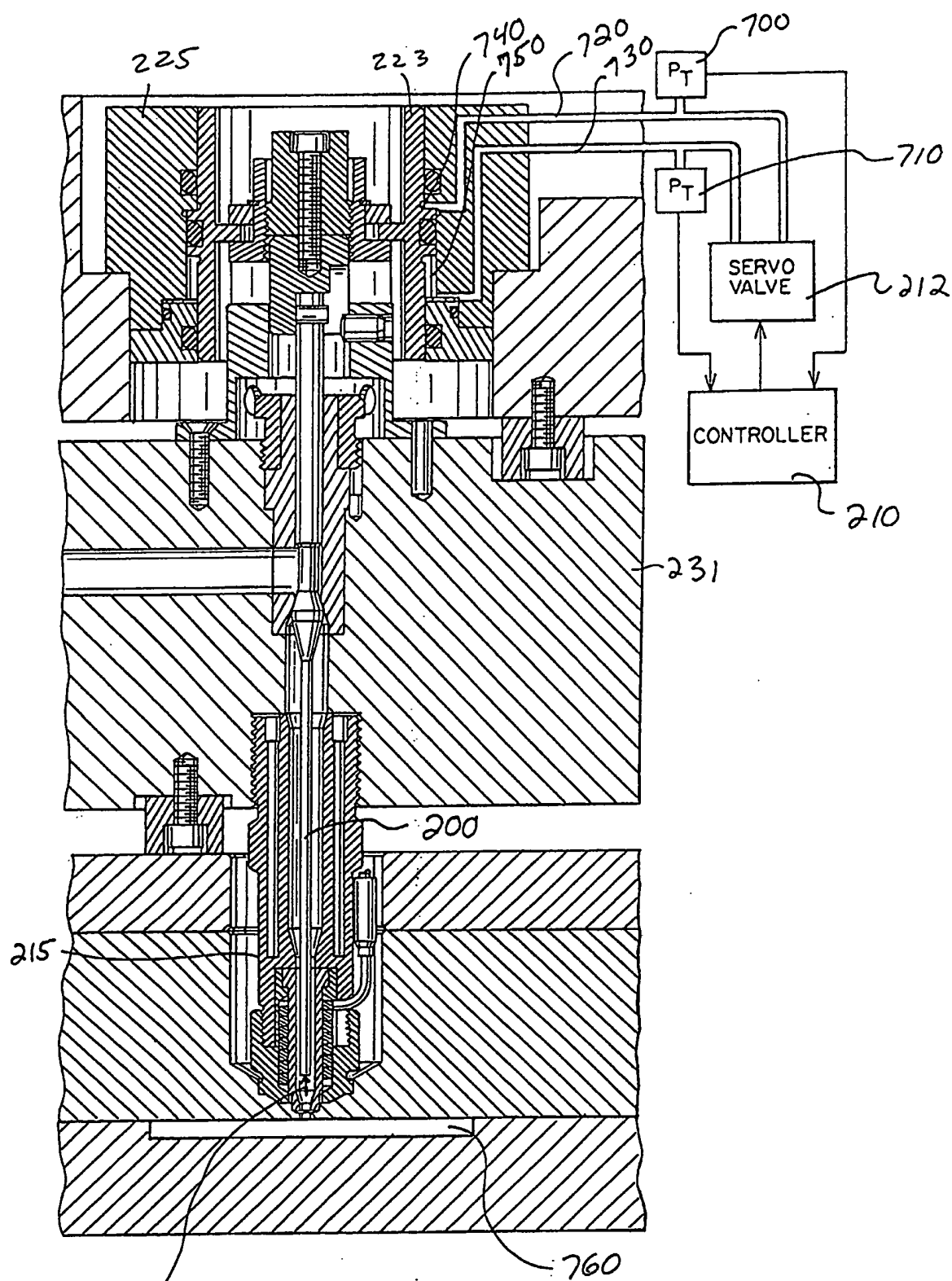
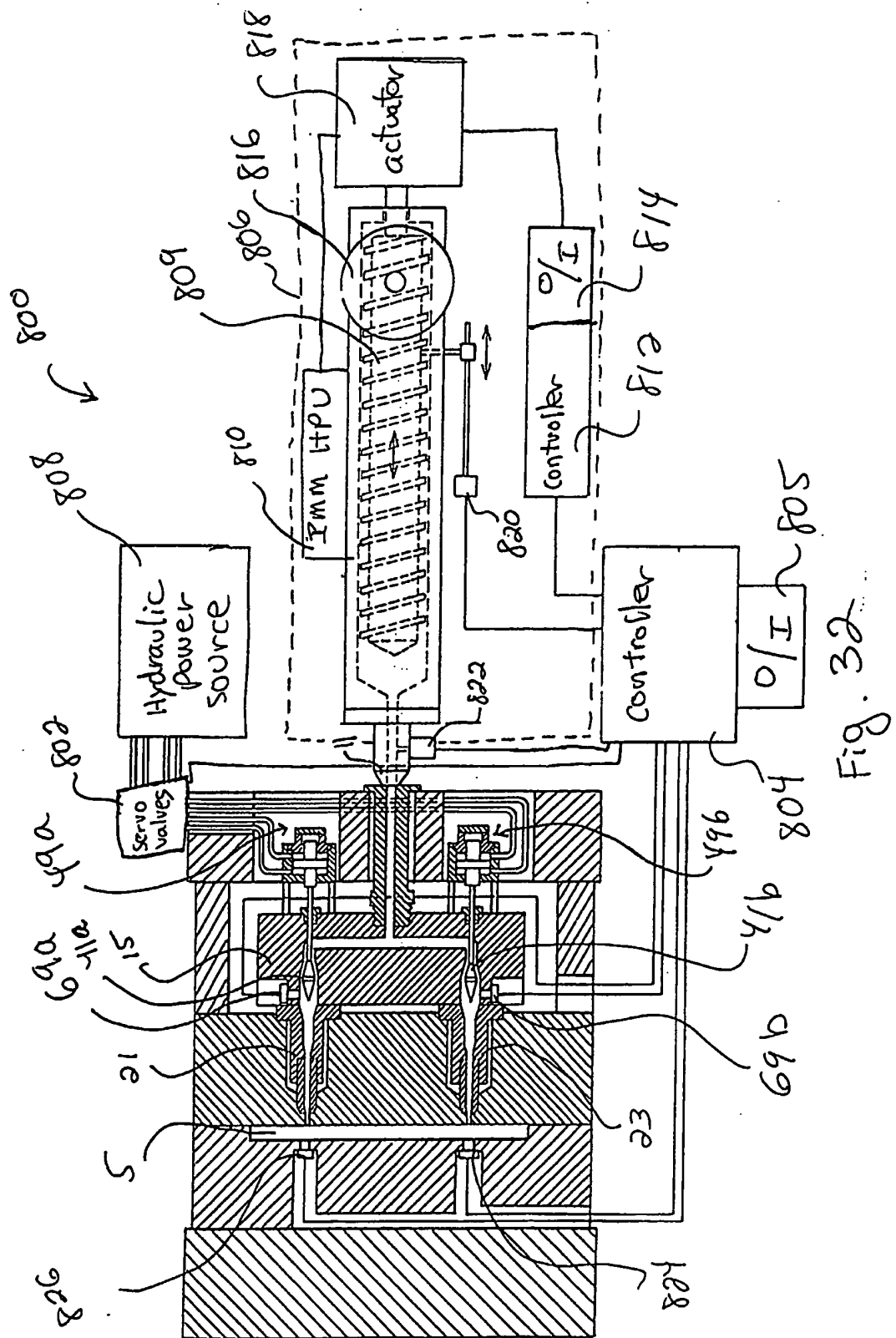


Fig. 31



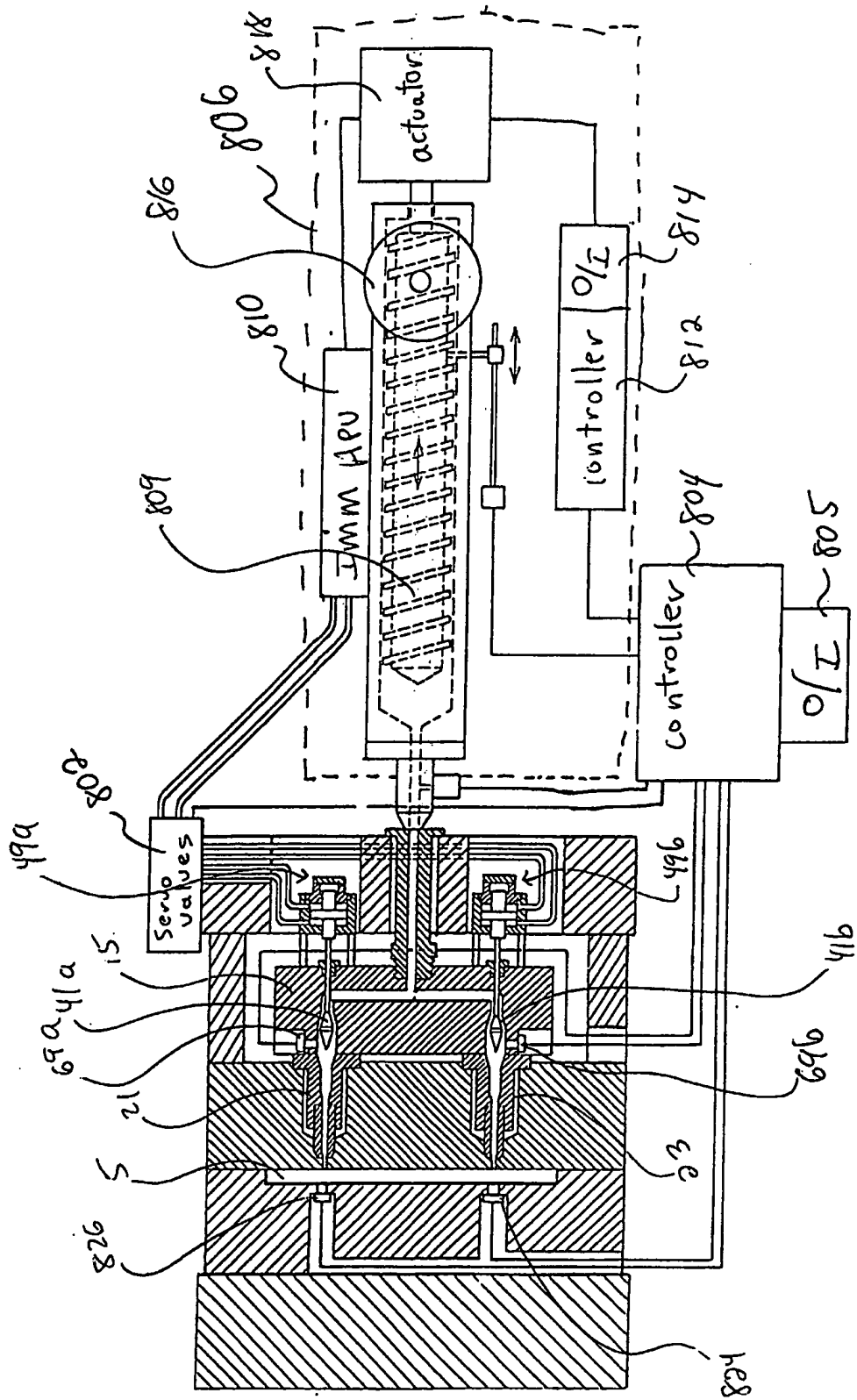


Fig. 33

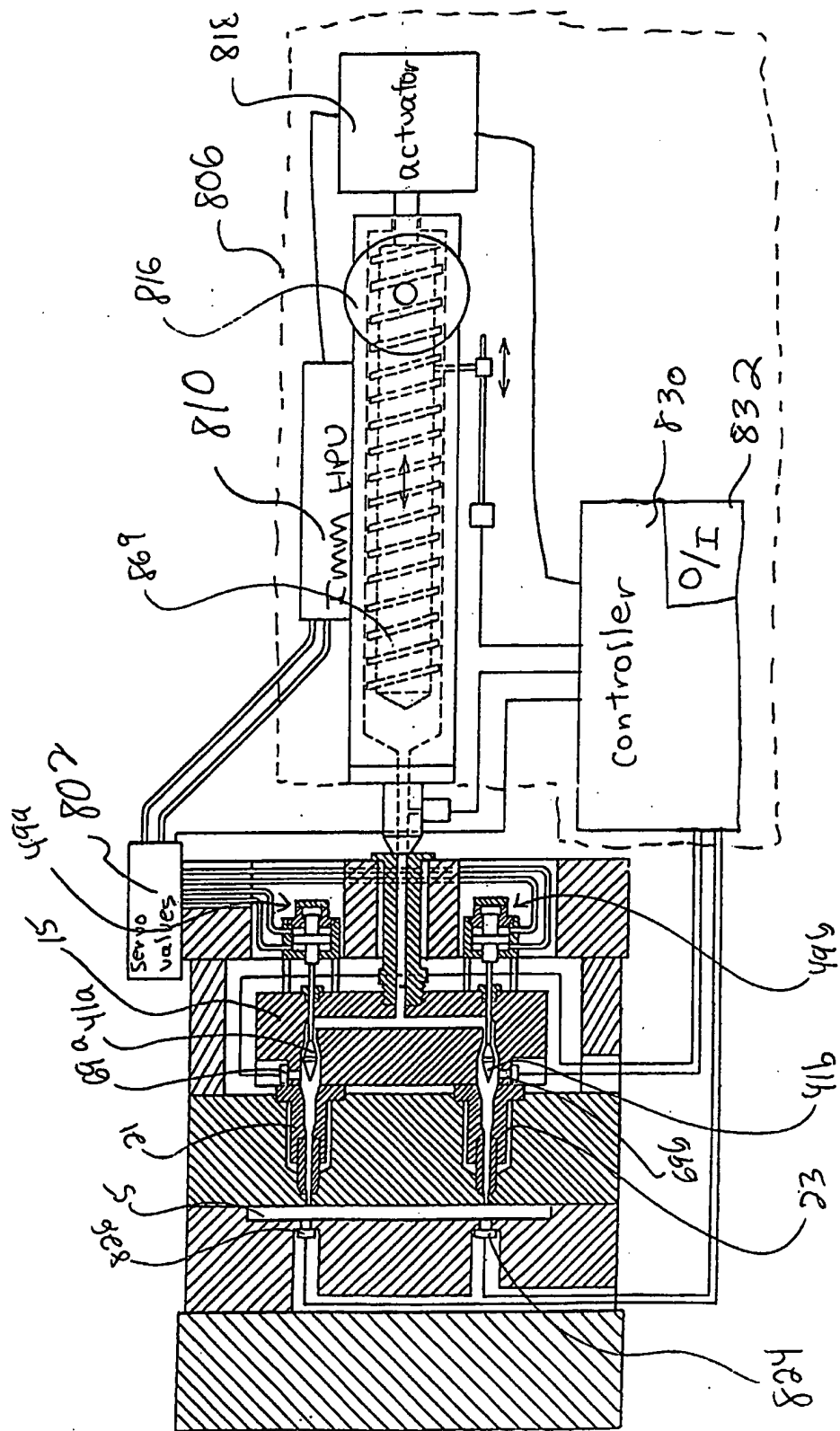


Fig 34

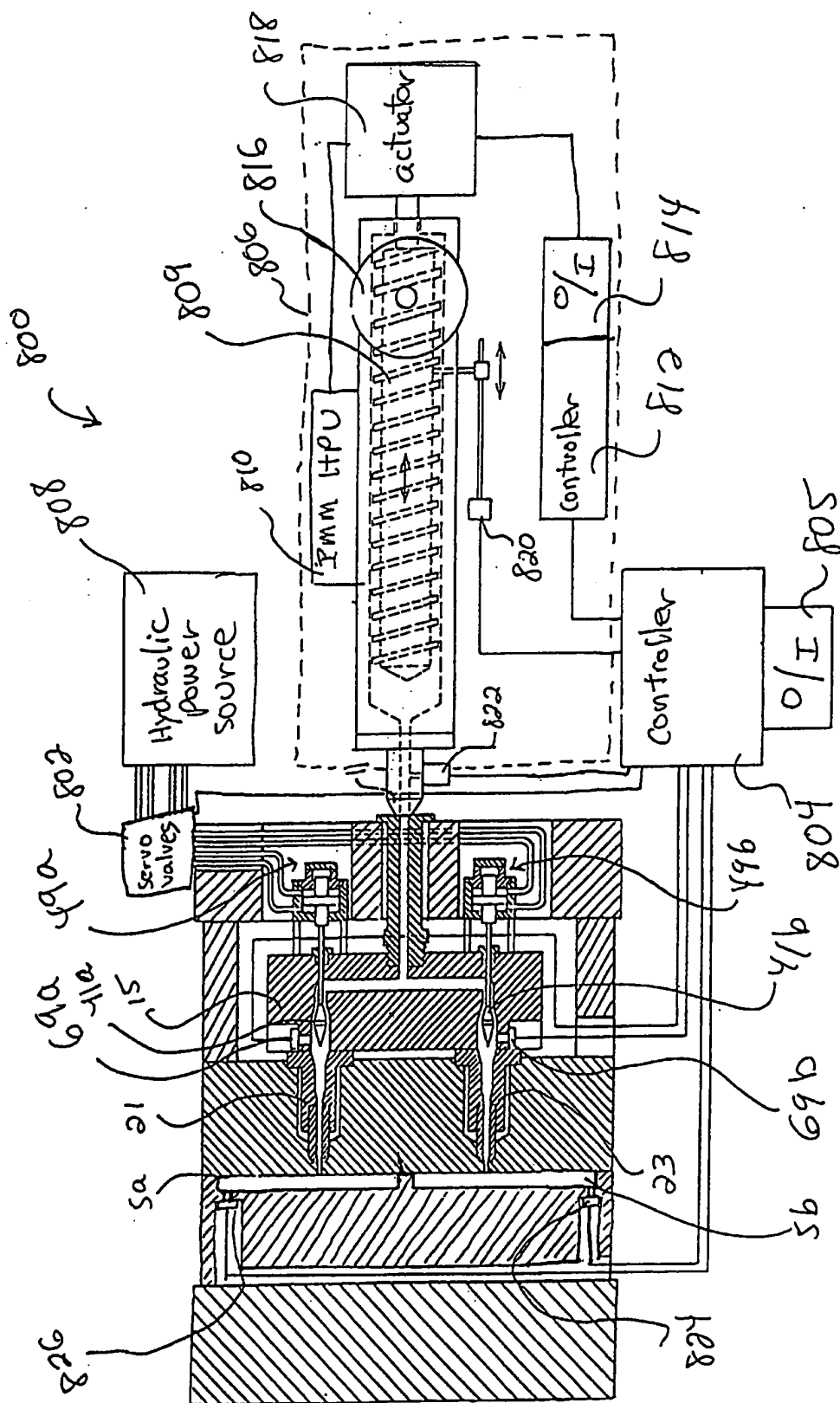


Fig. 35



## INTERNATIONAL SEARCH REPORT

Intern: Application No  
PCT/US 01/04674

## A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 B29C45/28 B29C45/30 B29C45/77

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 B29C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

PAJ

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	US 5 556 582 A (KAZMER DAVID O) 17 September 1996 (1996-09-17) the whole document	1-3,5,8, 9 11,15, 20,28, 29,31
X A	WO 98 56564 A (INCOE CORP.) 17 December 1998 (1998-12-17) the whole document	1-3,5, 8-10,15 11,20, 28,31
X A	DE 299 09 535 U (ENGEL MASCHINENBAU GMBH) 12 August 1999 (1999-08-12) the whole document	1-3,5,8, 9 11,15, 20,24, 28,30,31
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Further documents are listed in the continuation of box C.



Patent family members are listed in annex.

## \* Special categories of cited documents:

- \*A\* document defining the general state of the art which is not considered to be of particular relevance
- \*E\* earlier document but published on or after the international filing date
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- \*O\* document referring to an oral disclosure, use, exhibition or other means
- \*P\* document published prior to the international filing date but later than the priority date claimed

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- \*X\* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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- \*G\* document member of the same patent family

Date of the actual completion of the international search

11 June 2001

Date of mailing of the international search report

22/06/2001

Name and mailing address of the ISA

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Authorized officer

Bollen, J

## INTERNATIONAL SEARCH REPORT

 Intern:      Application No  
 PCT/US 01/04674

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	PATENT ABSTRACTS OF JAPAN vol. 10, no. 231 (M-506), 12 August 1986 (1986-08-12) & JP 61 063428 A (NIPPON DENSO CO LTD), 1 April 1986 (1986-04-01)	1-5
A	abstract	11,15, 20,24, 28,30,31
X	----- PATENT ABSTRACTS OF JAPAN vol. 7, no. 261 (M-257), 19 November 1983 (1983-11-19) -& JP 58 142833 A (KOBE SEIKOSHO KK), 25 August 1983 (1983-08-25)	1-5,20, 24
A	abstract	11,15, 28,30,31
X	----- PATENT ABSTRACTS OF JAPAN vol. 10, no. 66 (M-461), 15 March 1986 (1986-03-15) & JP 60 212321 A (YAZAKI KAKOU KK), 24 October 1985 (1985-10-24)	1-3,5
A	abstract	11,15, 20-23, 28,29,31
P,X	----- WO 01 08462 A (DYNISCO HOTRUNNERS INC. ) 8 February 2001 (2001-02-08)	1-5
A	the whole document	11,15, 20,28,31
A	----- WO 99 54109 A (DYNISCO HOTRUNNERS INC.) 28 October 1999 (1999-10-28) cited in the application	1-5,11, 15,20, 21,25, 26,28, 31-33
	the whole document -----	

# INTERNATIONAL SEARCH REPORT

Information on patent family members

Intern Application No  
PCT/US 01/04674

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
US 5556582	A	17-09-1996	NONE	
WO 9856564	A	17-12-1998	US 5919492 A AU 722465 B AU 7714798 A BR 9810256 A CN 1259076 T EP 0988140 A JP 2000515450 T US 6099767 A	06-07-1999 03-08-2000 30-12-1998 19-09-2000 05-07-2000 29-03-2000 21-11-2000 08-08-2000
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JP 61063428	A	01-04-1986	JP 1828002 C JP 5036215 B	28-02-1994 28-05-1993
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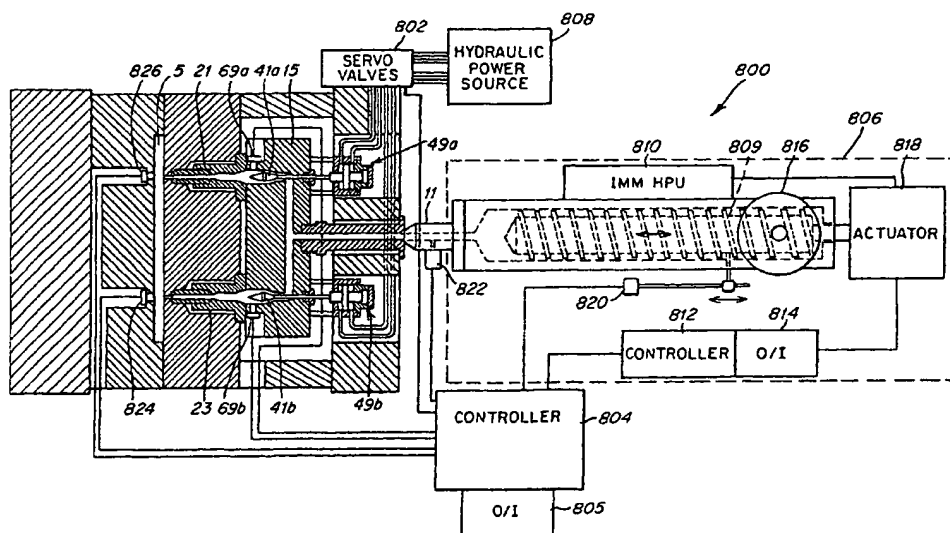
**PCT**

**(10) International Publication Number**  
**WO 01/060580 A1**

(75) Inventors/Applicants (for US only): **KAZMER, David**

[Continued on next page]

**(54) Title:** DYNAMIC FEED CONTROL SYSTEM



**(57) Abstract:** An injection molding apparatus and system are provided in which the rate of material flow during the injection cycle is controlled. According to one preferred embodiment, an injection molding system is provided that includes an injection molding machine including a hydraulic power source, a manifold for distributing material injected from said injection molding machine to a plurality of gates leading to one or more mold cavities, and a controller to individually control respective rates at which material is injected through said gates during an injection cycle. The controller is coupled to the hydraulic power source and the hydraulic power source supplies hydraulic power to both the injection molding machine and to control said respective rates.

**WO 01/060580 A1**



**Published:**

— with international search report

*For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.*

**(48) Date of publication of this corrected version:**

31 October 2002

**(15) Information about Correction:**

see PCT Gazette No. 44/2002 of 31 October 2002, Section II

## **DYNAMIC FEED CONTROL SYSTEM**

### **Related Applications**

5           This application is a Continuation-in-Part under 35 U.S.C. §120 of U.S. Application Serial No. 09/400,533, entitled "MANIFOLD SYSTEM HAVING FLOW CONTROL", filed September 21, 1999, which is a Continuation-in-Part of U.S. Application Serial No. 09/063,762, entitled "MANIFOLD SYSTEM HAVING FLOW  
10 CONTROL" filed April 21, 1998, and claims priority under 35 U.S.C. §119(e) to Provisional Application Serial No. 60/156,925, entitled "DYNAMIC FEED CONTROL" filed September 28, 1999.

### **Field of the Invention**

15           This invention relates to injection of pressurized materials through a manifold, such as injection molding of plastic melt in a hot runner system. More specifically, this invention relates to an improved injection molding hot runner system in which the rate of melt flow is controlled through the gate during an injection molding cycle.

### **Description of the Related Art**

20           United States Patent No. 5,556,582 discloses a multi-gate single cavity system in which the rate of melt flow through the individual gates is controlled independently via a control system according to specific target process conditions. This system enables the weld line of the part (the section of the part in which the melt from one gate meets the  
25 melt from another gate) to be selectively located. It also enables the shape of the weld line to be altered to form a stronger bond.

          The '582 patent discloses controlling the rate of melt flow with a tapered valve pin at the gate to the mold cavity. It also discloses placing a pressure transducer inside the mold cavity. Placing the pressure transducer inside the mold cavity can result in the  
30 pressure transducer sensing pressure spikes which can occur when the valve pin is closed. A pressure spike sensed by the transducer can cause an unintended response from the control system, and result in a less precise control of the melt flow than desired.

          The control system disclosed in the '582 patent uses the variables of valve pin position and cavity pressure to determine what position the valve pin should be in. Thus,

- 2 -

the algorithm performed by the control system in the '582 patent utilizes two variables to control the rate of melt flow into the cavity.

### **Summary of the Invention**

5           An injection molding apparatus and system are provided in which the rate of material flow during the injection cycle is controlled. According to one preferred embodiment, an injection molding system is provided that includes an injection molding machine including a hydraulic power source, a manifold for distributing material injected from said injection molding machine to a plurality of gates leading to one or more mold  
10       cavities, and a controller to individually control respective rates at which material is injected through said gates during an injection cycle. The controller is coupled to the hydraulic power source and the hydraulic power source supplies hydraulic power to both the injection molding machine and to control said respective rates.

          According to another embodiment, an injection molding system is provided that  
15       includes an injection molding machine, and a manifold for distributing material injected from said injection molding machine to a plurality of gates leading to one or more mold cavities. The injection molding machine includes a controller to individually control respective rates at which material is injected through said gates during an injection cycle.

          According to another embodiment, an injection molding system is provided that  
20       includes an injection molding machine, a manifold for distributing material injected from a nozzles of said injection molding machine to a plurality of gates leading to one or more mold cavities, a controller to individually control respective rates at which material is injected through said gates during an injection cycle, and a pressure transducer coupled to the nozzle of said injection molding machine. The controller receives pressure data  
25       from the pressure transducer.

          According to another embodiment, an injection molding system is provided that includes an injection molding machine, a manifold for distributing material injected from a plurality of nozzles of said injection molding machine to a plurality of gates leading to one or more mold cavities, a controller to individually control respective rates at which  
30       material is injected through said gates during an injection cycle, and a position transducer coupled to a screw of said injection molding machine. The controller receives position data of the screw from the position transducer.

- 3 -

According to another embodiment, an injection molding system is provided that includes an injection molding machine, a hot runner including a manifold and a plurality of injection nozzles for distributing material injected from said injection molding machine to a plurality of gates leading to one or more mold cavities, a controller to  
5 individually control respective rates at which material is injected through said gates during an injection cycle, and at least one pressure transducer mounted in the one or more cavities, the pressure transducer coupled to the controller to send pressure data to the controller. The controller alters the at least one respective rate from an injection pressure to a pack pressure when the pressure transducer detects a predetermined  
10 pressure value.

According to another embodiment, an injection molding system is provided that includes an injection molding machine, a hot runner including a manifold and a plurality of injection nozzles for distributing material injected from said injection molding machine to a plurality of gates leading to one or more mold cavities, a controller to  
15 individually control respective rates at which material is injected through said gates during an injection cycle, and at least one pressure transducer mounted in the one or more cavities, the pressure transducer coupled to the controller to send pressure data to the controller. The controller determines an end of the pack period of the injection cycle for at least one respective rate when the pressure transducer detects a predetermined  
20 pressure value.

According to another embodiment, an injection molding system is provided that includes an injection molding machine, a hot runner including a manifold and a plurality of injection nozzles for distributing material injected from said injection molding machine to a plurality of gates leading to one or more mold cavities, a plurality of  
25 pressure transducers coupled to said hot runner for sensing material pressure flowing to said gates, and at least one pressure transducer mounted in the one or more cavities, the pressure transducer to sense the material pressure inside the one or more cavities.

### **Brief Description of the Drawings**

30 Figure 1 is a partially schematic cross-sectional view of an injection molding system according to one embodiment of the present invention;



- 4 -

Figure 2 is an enlarged fragmentary cross-sectional view of one side of the injection molding system of Figure 1;

Figure 3 is an enlarged fragmentary cross-sectional view of an alternative embodiment of a system similar to Figure 1, in which a plug is used for easy removal of the valve pin;

Figure 4 is an enlarged fragmentary cross-sectional view of an alternative embodiment of a system similar to Figure 1, in which a threaded nozzle is used;

Figure 5 is a view similar to Figure 4, showing an alternative embodiment in which a plug is used for easy removal of the valve pin;

Figure 6 shows a fragmentary cross-sectional view of a system similar to Figure 1, showing an alternative embodiment in which a forward shut-off is used;

Figure 7 shows an enlarged fragmentary view of the embodiment of Figure 6, showing the valve pin in the open and closed positions, respectively;

Figure 8 is a cross-sectional view of an alternative embodiment of the present invention similar to Figure 6, in which a threaded nozzle is used with a plug for easy removal of the valve pin;

Figure 9 is an enlarged fragmentary view of the embodiment of Figure 8, in which the valve pin is shown in the open and closed positions;

Figure 10 is an enlarged view of an alternative embodiment of the valve pin, shown in the closed position;

Figure 11 is a fragmentary cross sectional view of an alternative embodiment of an injection molding system having flow control that includes a valve pin that extends to the gate;

Figure 12 is an enlarged fragmentary cross-sectional detail of the flow control area;

Figure 13 is a fragmentary cross sectional view of another alternative embodiment of an injection molding system having flow control that includes a valve pin that extends to the gate, showing the valve pin in the starting position prior to the beginning of an injection cycle;

Figure 14 is view of the injection molding system of Figure 13, showing the valve pin in an intermediate position in which material flow is permitted;

Figure 15 is a view of the injection molding system of Figure 13, showing the valve pin in the closed position at the end of an injection cycle; and

Figure 16 shows a series of graphs representing the actual pressure versus the target pressure measured in four injection nozzles coupled to a manifold as shown in  
5 Figure 13;

Figures 17 and 18 are screen icons displayed on interface 114 of Figure 13 which are used to display, create, edit, and store target profiles;

Figure 19 is a fragmentary cross-sectional partially schematic view of another alternative embodiment of an injection molding system having flow control in which a  
10 ram is used to inject material from a well in the manifold into the mold cavity;

Figure 20 is a fragmentary view of the embodiment shown in Figure 19 in which the well 640 is being filled by the injecting molding machine;

Figure 21 is a view similar to Figure 20 in which the well is full of material and the system is ready to inject material into the mold cavity;

15 Figure 22 is a view similar to Figures 20 and 21 in which injection into the mold cavity has begun;

Figure 23 is a view similar to Figures 20-22 in which the injection cycle is complete;

Figure 24 is a cross-sectional partially schematic view of another alternative  
20 embodiment of an injection molding system having flow control in which a load cell behind the valve pin is used to control the flow rate in each injection nozzle;

Figure 25 is an enlarged fragmentary cross-sectional view of the valve pin and actuator of Figure 24;

Figure 26 is an enlarged view of the load cell and valve pin of Figure 24;

25 Figures 27A and 27B show an enlarged view of the tip of the valve pin closing the gate and controlling the flow rate, respectively;

Figures 28A and 28B shown an alternative structure of an injection molding nozzle for use in the system shown in Figure 24;

Figure 29 is a cross-sectional partially schematic view of an alternative  
30 embodiment of an injection molding system having flow control similar to Figure 19 in which a pressure transducer is used to sense the hydraulic pressure supplied to the actuator;

- 6 -

Figure 30 shows a fragmentary cross-sectional view of an alternative embodiment of an injection molding system having flow control similar to Figure 13 in which the pressure transducer is mounted in the mold cavity; and

Figure 31 is a fragmentary cross-sectional view of an alternative embodiment of an injection molding system having flow control in which flow control is achieved by measuring the differential pressure of the actuator chambers.

Figure 32 is a schematic representation of an injection molding system utilizing the hot runner system shown in Figure 1;

Figure 33 is an alternative embodiment of the system of Figure 32 in which the hydraulic power source associated with the servo valves 802 has been integrated with the injection molding machine hydraulic power unit;

Figure 34 is an alternative embodiment of the injection molding systems shown in Figures 32 and 33 in which the controller 804 and operator interface 805 have been integrated in the injection molding machine controller 830 and interface 832; and

Figure 35 is an alternative embodiment of the injection molding system of Figure 32 in which the cavity pressure transducers 824 and 826 are located at the end of two mold cavities 5a and 5b.

### **Detailed Description**

Figures 1-2 show one embodiment of the injection molding system according to the present invention. The injection molding system 1 is a multi-gate single cavity system in which melt material 3 is injected into a cavity 5 from gates 7 and 9. Melt material 3 is injected from an injection molding machine 11 through an extended inlet 13 and into a manifold 15. Manifold 15 distributes the melt through channels 17 and 19. Although a hot runner system is shown in which plastic melt is injected, the invention is applicable to other types of injection systems in which it is useful to control the rate at which a material (e.g., metallic or composite materials) is delivered to a cavity.

Melt is distributed by the manifold through channels 17 and 19 and into bores 18 and 20 of nozzles 21 and 23, respectively. Melt is injected out of nozzles 21 and 23 and into cavity 5 (where the part is formed) which is formed by mold plates 25 and 27. Although a multi-gate single-cavity system is shown, the invention is not limited to this type of system, and is also applicable to, for example, multi-cavity systems, as discussed in greater detail below.

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The injection nozzles 21 and 23 are received in respective wells 28 and 29 formed in the mold plate 27. The nozzles 21 and 23 are each seated in support rings 31 and 33. The support rings serve to align the nozzles with the gates 7 and 9 and insulate the nozzles from the mold. The manifold 15 sits atop the rear end of the nozzles and maintains sealing contact with the nozzles via compression forces exerted on the assembly by clamps (not shown) of the injection molding machine. An O-ring 36 is provided to prevent melt leakage between the nozzles and the manifold. A dowel 73 centers the manifold on the mold plate 27. Dowels 32 and 34 prevent the nozzle 23 and support ring 33, respectively, from rotating with respect to the mold 27.

10       The nozzles also include a heater 35 (Figure 2). Although an electric band heater is shown, other heaters may be used. Furthermore, heat pipes (for example those disclosed in U.S. Patent No. 4,389,002) may be disposed in each nozzle and used alone or in conjunction with heater 35. The heater is used to maintain the melt material at its processing temperature up to the gates 7 and 9. The nozzles 21 and 23 also include an

15       insert 37 and a tip 39. The insert can be made of a material (for example beryllium copper) having high thermal conductivity in order to maintain the melt at its processing temperature up to the gate by imparting heat to the melt from the heater 35. The tip 39 is used to form a seal with the mold plate 27 and is preferably a material (for example titanium alloy or stainless steel) having low thermal conductivity so as to reduce heat

20       transfer from the nozzle to the mold.

      A valve pin 41 having a head 43 is used to control the rate of flow of the melt material to the respective gates 7 and 9. The valve pin reciprocates through the manifold. A valve pin bushing 44 is provided to prevent melt from leaking along stem 102 of the valve pin. The valve pin bushing is held in place by a threadably

25       mounted cap 46. The valve pin is opened at the beginning of the injection cycle and closed at the end of the cycle. During the cycle, the valve pin can assume intermediate positions between the fully open and closed positions, in order to decrease or increase the rate of flow of the melt. The head includes a tapered portion 45 that forms a gap 81 with a surface 47 of the bore 19 of the manifold. Increasing or decreasing the size of the gap

30       by displacing the valve pin correspondingly increases or decreases the flow of melt material to the gate. When the valve pin is closed the tapered portion 45 of the valve pin head contacts and seals with the surface 47 of the bore of the manifold.

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Figure 2 shows the head of the valve pin in a Phantom dashed line in the closed position and a solid line in the fully opened position in which the melt is permitted to flow at a maximum rate. To reduce the flow of melt, the pin is retracted away from the gate by an actuator 49, to thereby decrease the width of the gap 81 between the valve pin and the bore 19 of the manifold.

The actuator 49 (for example, the type disclosed in application serial no. 08/874,962) is mounted in a clamp plate 51 which covers the injection molding system 1. The actuator 49 is a hydraulic actuator, however, pneumatic or electronic actuators can be used. The actuator 49 includes a hydraulic circuit that includes a movable piston 53 in which the valve pin 41 is threadably mounted at 55. Thus, as the piston 53 moves, the valve pin 41 moves with it. The actuator 49 includes hydraulic lines 57 and 59 which are controlled by servo valves 1 and 2. Hydraulic line 57 is energized to move the valve pin 41 toward the gate to the open position, and hydraulic line 59 is energized to retract the valve pin away from the gate toward the close position. An actuator cap 61 limits longitudinal movement in the vertical direction of the piston 53. O-rings 63 provide respective seals to prevent hydraulic fluid from leaking out of the actuator. The actuator body 65 is mounted to the manifold via screws 67.

A pressure transducer 69 is used to sense the pressure in the manifold bore 19 downstream of the valve pin head 43. In operation, the conditions sensed by the pressure transducer 69 associated with each nozzle are fed back to a control system that includes controllers PID 1 and PID 2 and a CPU shown schematically in Figure 1. The CPU executes a PID (proportional, integral, derivative) algorithm which compares the sensed pressure (at a given time) from the pressure transducer to a programmed target pressure (for the given time). The CPU instructs the PID controller to adjust the valve pin using the actuator 49 in order to mirror the target pressure for that given time. In this way a programmed target pressure profile for an injection cycle for a particular part for each gate 7 and 9 can be followed.

Although in the disclosed embodiment the sensed condition is pressure, other sensed conditions can be used which relate to melt flow rate. For example, the position of the valve pin or the load on the valve pin could be the sensed condition. If so, a position sensor or load sensor, respectively, could be used to feed back the sensed condition to the PID controller. In the same manner as explained above, the CPU would

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use a PID algorithm to compare the sensed condition to a programmed target position profile or load profile for the particular gate to the mold cavity, and adjust the valve pin accordingly.

Melt flow rate is directly related to the pressure sensed in bore 19. Thus, using  
5 the controllers PID 1 and PID 2, the rate at which the melt flows into the gates 7 and 9 can be adjusted during a given injection molding cycle, according to the desired pressure profile. The pressure (and rate of melt flow) is decreased by retracting the valve pin and decreasing the width of the gap 81 between the valve pin and the manifold bore, while  
10 the pressure (and rate of melt flow) is increased by displacing the valve pin toward the gate 9, and increasing the width of the gap 81. The PID controllers adjust the position of the actuator piston 51 by sending instructions to servo valves 1 and 2.

By controlling the pressure in a single cavity system (as shown in Figure 1) it is possible to adjust the location and shape of the weld line formed when melt flow 75 from gate 7 meets melt flow 77 from gate 9 as disclosed in U.S. Patent No. 5,556,582.  
15 However, the invention also is useful in a multi-cavity system. In a multi-cavity system the invention can be used to balance fill rates and packing profiles in the respective cavities. This is useful, for example, when molding a plurality of like parts in different cavities. In such a system, to achieve a uniformity in the parts, the fill rates and packing profiles of the cavities should be as close to identical as possible. Using the same  
20 programmed pressure profile for each nozzle, unpredictable fill rate variations from cavity to cavity are overcome, and consistently uniform parts are produced from each cavity.

Another advantage of the present invention is seen in a multi-cavity system in which the nozzles are injecting into cavities which form different sized parts that require  
25 different fill rates and packing profiles. In this case, different pressure profiles can be programmed for each respective controller of each respective cavity. Still another advantage is when the size of the cavity is constantly changing, i.e., when making different size parts by changing a mold insert in which the part is formed. Rather than change the hardware (e.g., the nozzle) involved in order to change the fill rate and  
30 packing profile for the new part, a new program is chosen by the user corresponding to the new part to be formed.

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The embodiment of Figures 1 and 2 has the advantage of controlling the rate of melt flow away from the gate inside manifold 15 rather than at the gates 7 and 9. Controlling the melt flow away from the gate enables the pressure transducer to be located away from the gate (in Figures 1-5). In this way, the pressure transducer does not have to be placed inside the mold cavity, and is not susceptible to pressure spikes which can occur when the pressure transducer is located in the mold cavity or near the gate. Pressure spikes in the mold cavity result from the valve pin being closed at the gate. This pressure spike could cause an unintended response from the control system, for example, an opening of the valve pin to reduce the pressure — when the valve pin should be closed.

Avoidance of the effects of a pressure spike resulting from closing the gate to the mold makes the control system behave more accurately and predictably. Controlling flow away from the gate enables accurate control using only a single sensed condition (e.g., pressure) as a variable. The '582 patent disclosed the use of two sensed conditions (valve position and pressure) to compensate for an unintended response from the pressure spike. Sensing two conditions resulted in a more complex control algorithm (which used two variables) and more complicated hardware (pressure and position sensors).

Another advantage of controlling the melt flow away from the gate is the use of a larger valve pin head 43 than would be used if the valve pin closed at the gate. A larger valve pin head can be used because it is disposed in the manifold in which the melt flow bore 19 can be made larger to accommodate the larger valve pin head. It is generally undesirable to accommodate a large size valve pin head in the gate area within the end of the nozzle 23, tip 39 and insert 37. This is because the increased size of the nozzle, tip and insert in the gate area could interfere with the construction of the mold, for example, the placement of water lines within the mold which are preferably located close to the gate. Thus, a larger valve pin head can be accommodated away from the gate.

The use of a larger valve pin head enables the use of a larger surface 45 on the valve pin head and a larger surface 47 on the bore to form the control gap 81. The more "control" surface (45 and 47) and the longer the "control" gap (81) — the more precise control of the melt flow rate and pressure can be obtained because the rate of change of melt flow per movement of the valve pin is less. In Figures 1-3 the size of the gap and

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the rate of melt flow is adjusted by adjusting the width of the gap, however, adjusting the size of the gap and the rate of material flow can also be accomplished by changing the length of the gap, i.e., the longer the gap the more flow is restricted. Thus, changing the size of the gap and controlling the rate of material flow can be accomplished by changing the length or width of the gap.

The valve pin head includes a middle section 83 and a forward cone shaped section 95 which tapers from the middle section to a point 85. This shape assists in facilitating uniform melt flow when the melt flows past the control gap 81. The shape of the valve pin also helps eliminates dead spots in the melt flow downstream of the gap 81.

Figure 3 shows another aspect in which a plug 87 is inserted in the manifold 15 and held in place by a cap 89. A dowel 86 keeps the plug from rotating in the recess of the manifold that the plug is mounted. The plug enables easy removal of the valve pin 41 without disassembling the manifold, nozzles and mold. When the plug is removed from the manifold, the valve pin can be pulled out of the manifold where the plug was seated since the diameter of the recess in the manifold that the plug was in is greater than the diameter of the valve pin head at its widest point. Thus, the valve pin can be easily replaced without significant downtime.

Figures 4 and 5 show additional alternative embodiments of the invention in which a threaded nozzle style is used instead of a support ring nozzle style. In the threaded nozzle style, the nozzle 23 is threaded directly into manifold 15 via threads 91. Also, a coil heater 93 is used instead of the band heater shown in Figures 1-3. The threaded nozzle style is advantageous in that it permits removal of the manifold and nozzles (21 and 23) as a unitary element. There is also less of a possibility of melt leakage where the nozzle is threaded on the manifold. The support ring style (Figures 1-3) is advantageous in that one does not need to wait for the manifold to cool in order to separate the manifold from the nozzles. Figure 5 also shows the use of the plug 87 for convenient removal of valve pin 41.

Figures 6-10 show an alternative embodiment of the invention in which a "forward" shutoff is used rather than a retracted shutoff as shown in Figures 1-5. In the embodiment of Figures 6 and 7, the forward cone-shaped tapered portion 95 of the valve pin head 43 is used to control the flow of melt with surface 97 of the inner bore 20 of nozzle 23. An advantage of this arrangement is that the valve pin stem 102 does not



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restrict the flow of melt as in Figures 1-5. As seen in Figures 1-5, the clearance 100 between the stem 102 and the bore 19 of the manifold is not as great as the clearance 100 in Figures 6 and 7. The increased clearance 100 in Figures 6-7 results in a lesser pressure drop and less shear on the plastic.

5 In Figures 6 and 7 the control gap 98 is formed by the front cone-shaped portion 95 and the surface 97 of the bore 20 of the rear end of the nozzle 23. The pressure transducer 69 is located downstream of the control gap — thus, in Figures 6 and 7, the nozzle is machined to accommodate the pressure transducer as opposed to the pressure transducer being mounted in the manifold as in Figures 1-5.

10 Figure 7 shows the valve pin in solid lines in the open position and Phantom dashed lines in the closed position. To restrict the melt flow and thereby reduce the melt pressure, the valve pin is moved forward from the open position towards surface 97 of the bore 20 of the nozzle which reduces the width of the control gap 98. To increase the flow of melt the valve pin is retracted to increase the size of the gap 98.

15 The rear 45 of the valve pin head 43 remains tapered at an angle from the stem 102 of the valve pin 41. Although the surface 45 performs no sealing function in this embodiment, it is still tapered from the stem to facilitate even melt flow and reduce dead spots.

As in Figures 1-5, pressure readings are fed back to the control system (CPU and  
20 PID controller), which can accordingly adjust the position of the valve pin 41 to follow a target pressure profile. The forward shut-off arrangement shown in Figures 6 and 7 also has the advantages of the embodiment shown in Figures 1-5 in that a large valve pin head 43 is used to create a long control gap 98 and a large control surface 97. As stated above, a longer control gap and greater control surface provides more precise control of  
25 the pressure and melt flow rate.

Figures 8 and 9 show a forward shutoff arrangement similar to Figures 6 and 7, but instead of shutting off at the rear of the nozzle 23, the shut-off is located in the manifold at surface 101. Thus, in the embodiment shown in Figures 8 and 9, a conventional threaded nozzle 23 may be used with a manifold 15, since the manifold is  
30 machined to accommodate the pressure transducer 69 as in Figures 1-5. A spacer 88 is provided to insulate the manifold from the mold. This embodiment also includes a plug 87 for easy removal of the valve pin head 43.

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Figure 10 shows an alternative embodiment of the invention in which a forward shutoff valve pin head is shown as used in Figures 6-9. However, in this embodiment, the forward cone-shaped taper 95 on the valve pin includes a raised section 103 and a recessed section 104. Ridge 105 shows where the raised portion begins and the recessed section ends. Thus, a gap 107 remains between the bore 20 of the nozzle through which the melt flows and the surface of the valve pin head when the valve pin is in the closed position. Thus, a much smaller surface 109 is used to seal and close the valve pin. The gap 107 has the advantage in that it assists opening of the valve pin which is subjected to a substantial force  $F$  from the melt when the injection machine begins an injection cycle. When injection begins melt will flow into gap 107 and provide a force component  $F_1$  that assists the actuator in retracting and opening the valve pin. Thus, a smaller actuator, or the same actuator with less hydraulic pressure applied, can be used because it does not need to generate as much force in retracting the valve pin. Further, the stress forces on the head of the valve pin are reduced.

Despite the fact that the gap 107 performs no sealing function, its width is small enough to act as a control gap when the valve pin is open and correspondingly adjust the melt flow pressure with precision as in the embodiments of Figures 1-9.

Figures 11 and 12 show an alternative hot-runner system having flow control in which the control of melt flow is still away from the gate as in previous embodiments. Use of the pressure transducer 69 and PID control system is the same as in previous embodiments. In this embodiment, however, the valve pin 41 extends past the area of flow control via extension 110 to the gate. The valve pin is shown in solid lines in the fully open position and in Phantom dashed lines in the closed position. In addition to the flow control advantages away from the gate described above, the extended valve pin has the advantage of shutting off flow at the gate with a tapered end 112 of the valve pin 41.

Extending the valve pin to close the gate has several advantages. First, it shortens injection cycle time. In previous embodiments thermal gating is used. In thermal gating, plastification does not begin until the part from the previous cycle is ejected from the cavity. This prevents material from exiting the gate when the part is being ejected. When using a valve pin, however, plastification can be performed simultaneously with the opening of the mold when the valve pin is closed, thus

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shortening cycle time by beginning plastication sooner. Using a valve pin can also result in a smoother gate surface on the part.

The flow control area is shown enlarged in Figure 12. In solid lines the valve pin is shown in the fully open position in which maximum melt flow is permitted. The valve pin includes a convex surface 114 that tapers from edge 128 of the stem 102 of the valve pin 41 to a throat area 116 of reduced diameter. From throat area 116, the valve pin expands in diameter in section 118 to the extension 110 which extends in a uniform diameter to the tapered end of the valve pin.

In the flow control area the manifold includes a first section defined by a surface 120 that tapers to a section of reduced diameter defined by surface 122. From the section of reduced diameter the manifold channel then expands in diameter in a section defined by surface 124 to an outlet of the manifold 126 that communicates with the bore of the nozzle 20. Figures 11 and 12 show the support ring style nozzle similar to Figures 1-3. However, other types of nozzles may be used such as, for example, a threaded nozzle as shown in Figure 8.

As stated above, the valve pin is shown in the fully opened position in solid lines. In Figure 12, flow control is achieved and melt flow reduced by moving the valve pin 41 forward toward the gate thereby reducing the width of the control gap 98. Thus, surface 114 approaches surface 120 of the manifold to reduce the width of the control gap and reduce the rate of melt flow through the manifold to the gate.

To prevent melt flow from the manifold bore 19, and end the injection cycle, the valve pin is moved forward so that edge 128 of the valve pin, i.e., where the stem 102 meets the beginning of curved surface 114, will move past point 130 which is the beginning of surface 122 that defines the section of reduced diameter of the manifold bore 19. When edge 128 extends past point 130 of the manifold bore melt flow is prevented since the surface of the valve stem 102 seals with surface 122 of the manifold. The valve pin is shown in dashed lines where edge 128 is forward enough to form a seal with surface 122. At this position, however, the valve pin is not yet closed at the gate. To close the gate the valve pin moves further forward, with the surface of the stem 102 moving further along, and continuing to seal with, surface 122 of the manifold until the end 112 of the valve pin closes with the gate.

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In this way, the valve pin does not need to be machined to close the gate and the flow bore 19 of the manifold simultaneously, since stem 102 forms a seal with surface 122 before the gate is closed. Further, because the valve pin is closed after the seal is formed in the manifold, the valve pin closure will not create any unwanted pressure spikes. Likewise, when the valve pin is opened at the gate, the end 112 of the valve pin will not interfere with melt flow, since once the valve pin is retracted enough to permit melt flow through gap 98, the valve pin end 112 is a predetermined distance from the gate. The valve pin can, for example, travel 6 mm. from the fully open position to where a seal is first created between stem 102 and surface 122, and another 6 mm. to close the gate. Thus, the valve pin would have 12 mm. of travel, 6 mm. for flow control, and 6 mm. with the flow prevented to close the gate. Of course, the invention is not limited to this range of travel for the valve pin, and other dimensions can be used.

Figures 13-15 show another alternative hot runner system having flow control in which the control of material flow is away from the gate. Like the embodiment shown in Figures 11 and 12, the embodiment shown in Figures 13-15 also utilizes an extended valve pin design in which the valve pin closes the gate after completion of material flow. Unlike the embodiment of Figures 11 and 12, however, flow control is performed using a "reverse taper" pin design, similar to the valve pin design shown in Figures 1-5.

The valve pin 200 includes a reverse tapered control surface 205 for forming a gap 207 with a surface 209 of the manifold (see Figure 14). The action of displacing the pin 200 away from the gate 211 reduces the size of the gap 207. Consequently, the rate of material flow through bores 208 and 214 of nozzle 215 and manifold 231, respectively, is reduced, thereby reducing the pressure measured by the pressure transducer 217. Although only one nozzle 215 is shown, manifold 231 supports two or more like nozzle arrangements shown in Figs. 13-15, each nozzle for injecting into a single or multiple cavities.

The valve pin 200 reciprocates by movement of piston 223 disposed in an actuator body 225. This actuator is described in co-pending application Serial No. 08/874,962. As disclosed in that application, the use of this actuator enables easy access to valve pin 200 in that the actuator body 225 and piston 223 can be removed from the manifold and valve pin simple by releasing retaining ring 240.

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The reverse closure method offers an advantage over the forward closure method shown in Figures 6-9, 11 and 12, in that the action of the valve pin 200 moving away from the gate acts to displace material away from the gate, thereby assisting in the desired effect of decreasing flow rate and pressure.

5           In the forward closure method shown in Figures 6-9, forward movement of the pin is intended to reduce the control gap between the pin and the manifold (or nozzle) bore surface to thereby decrease flow rate and pressure. However, forward movement of the pin also tends to displace material toward the gate and into the cavity, thereby increasing pressure, working against the intended action of the pin to restrict flow.

10           Like the embodiment shown in Figures 6-9, and the embodiment shown in Figures 11 and 12, movement of the valve pin away from the gate is also intended to increase the flow rate and pressure. This movement, however, also tends to displace material away from the gate and decrease pressure. Accordingly, although either design can be used, the reverse taper design has been found to give better control stability in tracking the target pressure.

15           The embodiment shown in Figs. 13-15 also includes a tip heater 219 disposed about an insert 221 in the nozzle. The tip heater provides extra heat at the gate to keep the material at its processing temperature. The foregoing tip heater is described in United States Patent No. 5,871,786, entitled "Tip Heated Hot Runner Nozzle." Heat  
20           pipes 242 are also provided to conduct heat uniformly about the injection nozzle 215 and to the tip area. Heat pipes such as these are described in U.S. Patent No. 4,389,002.

          Figures 13-15 show the valve pin in three different positions. Figure 13 represents the position of the valve pin at the start of an injection cycle. Generally, an injection cycle includes: 1) an injection period during which substantial pressure is  
25           applied to the melt stream from the injection molding machine to inject the material in the mold cavity; 2) a reduction of the pressure from the injection molding machine in which melt material is packed into the mold cavity at a relatively constant pressure; and 3) a cooling period in which the pressure decreases to zero and the article in the mold solidifies.

30           Just prior to the start of injection, tapered control surface 205 is in contact with manifold surface 209 to prevent any material flow. At the start of injection the pin 200 will be opened to allow material flow. To start the injection cycle the valve pin 200 is

displaced toward the gate to permit material flow, as shown in Fig. 14. (Note: for some applications, not all the pins will be opened initially, for some gates pin opening will be varied to sequence the fill into either a single cavity or multiple cavities). Figure 15 shows the valve pin at the end of the injection cycle after pack. The part is ejected from the mold while the pin is in the position shown in Figure 15.

As in previous embodiments, pin position will be controlled by a controller 210 based on pressure readings fed to the controller from pressure sensor 217. In a preferred embodiment, the controller is a programmable controller, or "PLC," for example, model number 90-30PLC manufactured by GE-Fanuc. The controller compares the sensed pressure to a target pressure and adjusts the position of the valve pin via servo valve 212 to track the target pressure, displacing the pin forward toward the gate to increase material flow (and pressure) and withdrawing the pin away from the gate to decrease material flow (and pressure). In a preferred embodiment, the controller performs this comparison and controls pin position according to a PID algorithm. Furthermore, as an alternative, valve 212 can also be a high speed proportional valve.

The controller also performs these functions for the other injection nozzles (not shown) coupled to the manifold 231. Associated with each of these nozzles is a valve pin or some type of control valve to control the material flow rate, a pressure transducer, an input device for reading the output signal of the pressure transducer, means for signal comparison and PID calculation (e.g., the controller 210), means for setting, changing and storing a target profile (e.g., interface 214), an output means for controlling a servo valve or proportional valve, and an actuator to move the valve pin. The actuator can be pneumatic, hydraulic or electric. The foregoing components associated with each nozzle to control the flow rate through each nozzle are called a control zone or axis of control. Instead of a single controller used to control all control zones, alternatively, individual controllers can be used in a single control zone or group of control zones.

An operator interface 214, for example, a personal computer, is used to program a particular target pressure profile into controller 210. Although a personal computer is used, the interface 214 can be any appropriate graphical or alpha numeric display, and could be directly mounted to the controller. As in previous embodiments, the target profile is selected for each nozzle and gate associated therewith by pre-selecting a target profile (preferably including at least parameters for injection pressure, injection time,

pack pressure and pack time), programming the target profile into controller 210, and running the process.

In the case of a multicavity application in which different parts are being produced in independent cavities associated with each nozzle (a "family tool" mold), it is preferable to create each target profile separately, since different shaped and sized cavities can have different profiles which produce good parts.

For example, in a system having a manifold with four nozzles coupled thereto for injecting into four separate cavities, to create a profile for a particular nozzle and cavity, three of the four nozzles are shut off while the target profile is created for the fourth. Three of the four nozzles are shut off by keeping the valve pins in the position shown in Figs. 13 or 15 in which no melt flow is permitted into the cavity.

To create the target profile for the particular nozzle and cavity associated therewith, the injection molding machine is set at maximum injection pressure and screw speed, and parameters relating to the injection pressure, injection time, pack pressure and pack time are set on the controller 210 at values that the molder estimates will generate good parts based on part size, shape, material being used, experience, etc. Injection cycles are run for the selected nozzle and cavity, with alterations being made to the above parameters depending on the condition of the part being produced. When satisfactory parts are produced, the profile that produced the satisfactory parts is determined for that nozzle and cavity associated therewith.

This process is repeated for all four nozzles (keeping three valve pins closed while the selected nozzle is profiled) until target profiles are ascertained for each nozzle and cavity associated therewith. Preferably, the acceptable target profiles are stored in computer member, for example, on a file stored in interface 214 and used by controller 210 for production. The process can then be run for all four cavities using the four particularized profiles.

Of course, the foregoing process of profile creation is not limited to use with a manifold having four nozzles, but can be used with any number of nozzles. Furthermore, although it is preferable to profile one nozzle and cavity at a time (while the other nozzles are closed) in a "family tool" mold application, the target profiles can also be created by running all nozzles simultaneously, and similarly adjusting each nozzle profile according the quality of the parts produced. This would be preferable in an

application where all the nozzles are injecting into like cavities, since the profiles should be similar, if not the same, for each nozzle and cavity associated therewith.

In single cavity applications (where multiple nozzles from a manifold are injecting into a single cavity), the target profiles would also be created by running the nozzles at the same time and adjusting the profiles for each nozzle according to the quality of the part being produced. The system can also be simplified without using interface 214, in which each target profile can be stored on a computer readable medium in controller 210, or the parameters can be set manually on the controller.

Fig. 14 shows the pin position in a position that permits material flow during injection and/or pack. As described above, when the target profile calls for an increase in pressure, the controller will cause the valve pin 200 to move forward to increase gap 207, which increases material flow, which increases the pressure sensed by pressure transducer 217. If the injection molding machine is not providing adequate pressure (i.e., greater than the target pressure), however, moving the pin forward will not increase the pressure sensed by transducer 217 enough to reach the target pressure, and the controller will continue to move the pin forward calling for an increase in pressure. This could lead to a loss of control since moving the pin further forward will tend to cause the head 227 of the valve pin to close the gate and attenuate material flow through and about the gate.

Accordingly, to prevent loss of control due to inadequate injection pressure, the output pressure of the injection molding machine can be monitored to alert an operator when the pressure drops below a particular value relative to the target pressure. Alternatively, the forward stroke of the valve pin (from the position in Figure 13 to the position in Figure 14) can be limited during injection and pack. In a preferred embodiment, the pin stroke is limited to approximately 4 millimeters. Greater or smaller ranges of pin movement can be used depending on the application. If adequate injection pressure is not a problem, neither of these safeguards is necessary.

To prevent the movement of the valve pin too far forward during injection and pack several methods can be used. For example, a control logic performed by the controller 210 can be used in which the output signal from the controller to the servo valve is monitored. Based on this signal, an estimate of the valve pin position is made. If the valve pin position exceeds a desired maximum, for example, 4 millimeters, then the forward movement of the pin is halted, or reversed slightly away from the gate. At



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the end of the injection cycle, the control logic is no longer needed, since the pin is moved to the closed position of Figure 15 and attenuation of flow is no longer a concern. Thus, at the end of the pack portion of the injection cycle, a signal is sent to the servo valve to move the pin forward to the closed position of Fig. 15.

5        Other methods and apparatus for detecting and limiting forward displacement of the valve pin 200 can be used during injection and pack. For example, the pressure at the injection molding machine nozzle can be measured to monitor the material pressure supplied to the manifold. If the input pressure to the manifold is less than the target pressure, or less than a specific amount above the target pressure, e.g., 500 p.s.i., an error  
10    message is generated.

Another means for limiting the forward movement of the pin is a mechanical or proximity switch which can be used to detect and limit the displacement of the valve pin towards the gate instead of the control logic previously described. The mechanical or proximity switch indicates when the pin travels beyond the control range (for example, 4  
15    millimeters). If the switch changes state, the direction of the pin travel is halted or reversed slightly to maintain the pin within the desired range of movement.

Another means for limiting the forward movement of the pin is a position sensor, for example, a linear voltage differential transformer (LVDT) that is mounted onto the pin shaft to give an output signal proportional to pin distance traveled. When the output  
20    signal indicates that the pin travels beyond the control range, the movement is halted or reversed slightly.

Still another means for limiting the forward movement of the pin is an electronic actuator. An electronic actuator is used to move the pin instead of the hydraulic or pneumatic actuator shown in Figures 13-15. An example of a suitable electronic actuator  
25    is shown in co-pending U.S. Serial No. 09/187,974. Using an electronic actuator, the output signal to the servo valve motor can be used to estimate pin position, or an encoder can be added to the motor to give an output signal proportional to pin position. As with previous options, if the pin position travels beyond the control range, then the direction is reversed slightly or the position maintained.

30        At the end of the pack portion of the injection cycle, the valve pin 200 is moved all the way forward to close off the gate as shown in Fig. 15. In the foregoing example, the full stroke of the pin (from the position in Figure 13 to the position in Figure 15) is

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approximately 12 millimeters. Of course, different ranges of movement can be used depending on the application.

The gate remains closed until just prior to the start of the next injection cycle when it is opened and moved to the position shown in Fig. 13. While the gate is closed, as shown in Fig. 15, the injection molding machine begins plastication for the next injection cycle as the part is cooled and ejected from the mold.

Fig. 16 shows time versus pressure graphs (235, 237, 239, 241) of the pressure detected by four pressure transducers associated with four nozzles mounted in manifold block 231. The four nozzles are substantially similar to the nozzle shown in Figures 13-15, and include pressure transducers coupled to the controller 210 in the same manner as pressure transducer 217.

The graphs of Figure 16 (a-d) are generated on the user interface 214 so that a user can observe the tracking of the actual pressure versus the target pressure during the injection cycle in real time, or after the cycle is complete. The four different graphs of Figure 16 show four independent target pressure profiles ("desired") emulated by the four individual nozzles. Different target profiles are desirable to uniformly fill different sized individual cavities associated with each nozzle, or to uniformly fill different sized sections of a single cavity. Graphs such as these can be generated with respect to any of the previous embodiments described herein.

The valve pin associated with graph 235 is opened sequentially at .5 seconds after the valves associated with the other three graphs (237, 239 and 241) were opened at .00 seconds. Referring back to Figures 13-15, just before opening, the valve pins are in the position shown in Figure 13, while at approximately 6.25 seconds at the end of the injection cycle all four valve pins are in the position shown in Figure 15. During injection (for example, .00 to 1.0 seconds in Fig. 16b) and pack (for example, 1.0 to 6.25 seconds in Fig. 16b) portions of the graphs, each valve pin is controlled to a plurality of positions to alter the pressure sensed by the pressure transducer associated therewith to track the target pressure.

Through the user interface 214, target profiles can be designed, and changes can be made to any of the target profiles using standard windows-based editing techniques. The profiles are then used by controller 210 to control the position of the valve pin. For

example, Fig. 17 shows an example of a profile creation and editing screen icon 300 generated on interface 214.

Screen icon 300 is generated by a windows-based application performed on interface 214. Alternatively, this icon could be generated on an interface associated with controller 210. Screen icon 300 provides a user with the ability to create a new target profile or edit an existing target profile for any given nozzle and cavity associated therewith. Screen icon 300 and the profile creation text techniques described herein are described with reference to Figures 13-15, although they are applicable to all embodiments described herein.

A profile 310 includes (x, y) data pairs, corresponding to time values 320 and pressure values 330 which represent the desired pressure sensed by the pressure transducer for the particular nozzle being profiled. The screen icon shown in Figure 17 is shown in a "basic" mode in which a limited group of parameters are entered to generate a profile. For example, in the foregoing embodiment, the "basic" mode permits a user to input start time displayed at 340, maximum fill pressure displayed at 350 (also known as injection pressure), the start of pack time displayed at 360, the pack pressure displayed at 370, and the total cycle time displayed at 380.

The screen also allows the user to select the particular valve pin they are controlling displayed at 390, and name the part being molded displayed at 400. Each of these parameters can be adjusted independently using standard windows-based editing techniques such as using a cursor to actuate up/down arrows 410, or by simply typing in values on a keyboard. As these parameters are entered and modified, the profile will be displayed on a graph 420 according to the parameters selected at that time.

By clicking on a pull-down menu arrow 391, the user can select different nozzle valves in order to create, view or edit a profile for the selected nozzle valve and cavity associated therewith. Also, a part name 400 can be entered and displayed for each selected nozzle valve.

The newly edited profile can be saved in computer memory individually, or saved as a group of profiles for a group of nozzles that inject into a particular single or multi-cavity mold. The term "recipe" is used to describe a group of profiles for a particular mold and the name of the particular recipe is displayed at 430 on the screen icon.

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To create a new profile or edit an existing profile, first the user selects a particular nozzle valve of the group of valves for the particular recipe group being profiled. The valve selection is displayed at 390. The user inputs an alpha/numeric name to be associated with the profile being created, for family tool molds this may be called a part name displayed at 400. The user then inputs a time displayed at 340 to specify when injection starts. A delay can be with particular valve pins to sequence the opening of the valve pins and the injection of melt material into different gates of a mold.

The user then inputs the fill (injection) pressure displayed at 350. In the basic mode, the ramp from zero pressure to max fill pressure is a fixed time, for example, .3 seconds. The user next inputs the start pack time to indicate when the pack phase of the injection cycle starts. The ramp from the filling phase to the packing phase is also fixed time in the basic mode, for example, .3 seconds.

The final parameter is the cycle time which is displayed at 380 in which the user specifies when the pack phase (and the injection cycle) ends. The ramp from the pack phase to zero pressure will be instantaneous when a valve pin is used to close the gate, as in the embodiment of Figure 13, or slower in a thermal gate (see Figure 1) due to the residual pressure in the cavity which will decay to zero pressure once the part solidifies in the mold cavity.

User input buttons 415 through 455 are used to save and load target profiles. Button 415 permits the user to close the screen. When this button is clicked, the current group of profiles will take effect for the recipe being profiled. Cancel button 425 is used to ignore current profile changes and revert back to the original profiles and close the screen. Read Trace button 435 is used to load an existing and saved target profile from memory. The profiles can be stored in memory contained in the interface 215 or the controller 210. Save trace button 440 is used to save the current profile. Read group button 445 is used to load an existing recipe group. Save group button 450 is used to save the current group of target profiles for a group of nozzle valve pins. The process tuning button 455 allows the user to change the PID settings (for example, the gains) for a particular nozzle valve in a control zone. Also displayed is a pressure range 465 for the injection molding application.

Button 460 permits the user to toggle to an "advanced" mode profile creation and editing screen. The advanced profile creation and editing screen is shown in Figure 18.

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The advanced mode allows a greater number of profile points to be inserted, edited, or deleted than the basic mode. As in the basic mode, as the profile is changed, the resulting profile is displayed.

The advanced mode offers greater profilability because the user can select values  
5 for individual time and pressure data pairs. As shown in the graph 420, the profile 470 displayed is not limited to a single pressure for fill and pack, respectively, as in the basic mode. In the advanced mode, individual (x, y) data pairs (time and pressure) can be selected anywhere during the injection cycle.

To create and edit a profile using advanced mode, the user can select a plurality  
10 of times during the injection cycle (for example 16 different times), and select a pressure value for each selected time. Using standard windows-based editing techniques (arrows 475) the user assigns consecutive points along the profile (displayed at 478), particular time values displayed at 480 and particular pressure values displayed at 485.

The next button 490 is used to select the next point on the profile for editing.  
15 Prev button 495 is used to select the previous point on the profile for editing. Delete button 500 is used for deleting the currently selected point. When the delete button is used the two adjacent points will be redrawn showing one straight line segment.

The add button 510 is used to add a new point after the currently selected point in which time and pressure values are entered for the new point. When the add button is  
20 used the two adjacent points will be redrawn showing two segments connecting to the new point.

Figures 19-23 show another alternative embodiment of an injection molding system. The system includes a manifold 515 having a plurality of nozzles 520 coupled thereto for injecting melt material into a plurality of cavities 525. Alternatively, the  
25 nozzles can also inject into a single cavity. In Figure 19, only one nozzle 520 is shown but the following description applies to all nozzles coupled to manifold 515.

As in previous embodiments, each nozzle in the system includes a pressure transducer 530 associated therewith for sensing the pressure of the melt material in the manifold which thereby gives an indication of rate of meltflow through nozzle 520 and  
30 into cavity 525 with respect to each injection molding nozzle. Mold cavity 525 is formed by mold halves 526 and 527, which are separated to eject the molded part formed

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in cavity 525 after the injection cycle. As in previous embodiments, the pressure transducer can also be located in the nozzle, the manifold, or the cavity.

As in previous embodiments, a controller 535 receives signals from pressure transducers 530 coupled to each nozzle 520 (only one of which is shown). The  
5 controller 535 controls solenoid valve 540 which controls the movement of a piston in actuator 545 which is coupled to and acts to reciprocate the valve pin 550 to open and close gate 555 to cavity 525.

The controller also sends a signal to servo valve 560A which controls actuator 560 which in turn controls the movement of a ram 565, and further controls solenoid  
10 valve 570 which is coupled to another actuator 575 which controls a valve 580 which is adapted to open and close a manifold channel 585 which leads to nozzle 520. Each injection nozzle coupled to manifold 515 (not shown) includes the foregoing actuators 545, 575 and 560 and ram 565 and solenoid valves 540 and 570 and servo valve 560A associated therewith for controlling flow from each nozzle.

15 The actuators are mounted in a clamp plate 595 which also includes an opening 600 that receives an inlet bushing 610 threadably mounted to the manifold 515. The inlet bushing 610 receives a nozzle 590 from an injection molding machine. The injection molding machine can be, for example, a reciprocating or non-reciprocating extruder. The injection molding machine nozzle 590 feeds melt material into the central  
20 bushing 610 into a central channel 620 which branches off via a plurality of channels 585 and 630 (and others not shown) to a corresponding plurality of injection molding nozzles 520.

The foregoing embodiment is similar to previous embodiments in that pressure transducer 530 is used to measure pressure indicative of flow rate of melt material into  
25 cavity 525 during the injection cycle. (The actuators described herein are hydraulic actuators, however, pneumatic or electric or other types of actuation can also be used.) Also, as in previous embodiments, a controller 535 compares the pressure sensed by the pressure transducer to target values of a target profile and issues control signals to increase or decrease pressure to track the target profile for each nozzle.

30 In previous embodiments the controller controlled the position of a valve pin to regulate flow rate independently at each gate during injection. The foregoing embodiment also enables the flow rate of plastic to be controlled independently through

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each nozzle 520 and each gate during injection. However, in the embodiment shown in Figures 19-23, a valve pin is not used to control flow rate as in previous embodiments. Rather, valve pin 550 is used only to open and close gate 555.

5 In the foregoing embodiment, ram 565 and well 640 are used to regulate the flow of melt material through nozzle 520 and into cavity 525 in the following manner.

At the start of the injection cycle, valve gate 555 is closed by valve pin 550 and valve 580 is opened to permit flow through manifold channel 585 (see Figure 20). The injection molding machine nozzle 590 injects melt material through the inlet bushing 610 into the manifold 515, such that it fills well 640 (see Figure 20). The valve pin 550 is  
10 still in the closed position while the well 640 is being filled. Ram 565 is in a predetermined adjustable retracted position to permit a specific volume of melt material to gather in well 640 (see Figure 21). Figure 21 shows the system ready to inject melt material into cavity 525.

The controller 535 then signals the servo valve 540 to cause actuator 545 to  
15 retract valve pin 550 and open gate 555, while also signaling servo valve 570 to cause actuator 575 to close valve 580 and shut off manifold channel 585. Closing valve 580 when injecting into the cavity prevents backflow of material through channel 585. This position is shown in Figure 22.

The controller then signals actuator 560 to move ram 565 forward to inject  
20 material from the well 640 through the nozzle 520 and into the cavity 525. During this time, the controller controls the velocity at which the ram moves forward, according to the pressure sensed by pressure transducer 530, in relation to a target pressure profile. Accordingly, if the pressure transducer 530 senses a pressure that is below the target pressure for that particular time during the injection cycle, the controller 535 signals the  
25 actuator 560 to increase the velocity of the ram 565, conversely, if the pressure sensed is greater than the target pressure, the controller will control the actuator to decrease the velocity of the ram forward. When the ram reaches its lowermost position, the cavity 525 is full and the gate is closed (see Figure 23). Alternatively, ram 565 can be velocity controlled by using a linear transducer to monitor ram position. If so, at the end of  
30 injection, the ram is not bottomed out, and control can be transferred to the pressure transducer 530 during pack.

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As stated above, a reciprocating or non-reciprocating extruder can be used. If a non-reciprocating extruder is used, plastification into the manifold can be continuous, and the valve 580 is used to shut off the manifold channel 585 during injection so that during this time no plastic can flow through the manifold channel. When well 640 is filled with melt material, plastification in the non-reciprocating extruder can be stopped until the next cycle.

As in previous embodiments described herein, preferably a PID algorithm is used to control the actuator 560 to track the target profile. The target profile can be created in the same manner as described above with respect to previous embodiments.

Using the embodiment shown in Figures 19-23, the flow rate of plastic through each gate is controlled independently. Additionally, the use of well 640 enables one to control the specific volume of plastic injected into each cavity 525, which leads to part-to-part consistency, especially when molding in multi-cavity applications in which each cavity 525 is an identical part. By altering the position of ram 565 when injecting melt material into well 640, the volume of material in well 640 can be controlled, thereby controlling the volume of material into cavity 525.

Figures 24-28 show an alternative embodiment in which a load cell 140 is used to sense the melt pressure acting on the face 142 of valve pin 41. Where possible, reference characters are used that refer to elements common to Figure 1. As in previous embodiments, an actuator 49 is used to translate the valve pin 41 toward and away from the gate. The actuator 49 includes a housing 144 and a piston 146 slidably mounted within the housing. The actuator is fed by pneumatic or hydraulic lines 148 and 150. Other actuators, for example, electrical actuators may also be used.

The valve pin 41 is mounted to the piston 146 so that valve pin translates through the injection nozzle 23 with movement of the piston. The valve pin is mounted to the piston via a pin 152. The pin 152 is slotted so that a clearance 154 exists in which the valve pin can translate with respect to the pin 152 and piston 146. The valve pin bears against a button 156 on the load cell 140. The load cell 140 is mounted via screws 158 to the piston. Thus, as shown in Figure 26, a force F2 acting on the valve pin will cause the load button 156 to depress. Excitation voltages or other types of signals which indicate the proportionate force on the load button 156 are carried through cable 160 and fed to a controller 151.



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In operation, as seen in Figure 24, the melt material is injected from an injection molding machine nozzle 11 into an extended inlet 13 mounted to a manifold 15 through respective injection molding nozzles 21 and 23 and into mold cavities 162 and 164. In the embodiment shown, a multi-cavity mold is shown in which nozzles 21 and 23 inject melt material to form different size molded parts in cavities 162 and 164, respectively. As stated above with respect to the embodiment shown in Figure 1, a mold cavity with multiple gates can be used, or multiple mold cavities with cavities having the same size can be used.

When the valve pin 41 is retracted to permit melt material to be injected into the cavity 162, the melt pressure will act on the face of the valve pin 142 with the resulting force being transmitted through the shaft of the valve pin to the load sensor 140 (see Figures 26-27). Thus, the load (F2) sensed by load cell 140 is directly related to the melt flow rate into the melt cavity.

Shear stresses caused by the melt streaming downward over the valve pin will tend to reduce the pressure sensed by the load cell but such stresses are typically less than the nominal load due to the melt pressure. Thus, the resultant force F2 will tend to compress the valve pin toward the load cell, with the possible exception of the initial opening of the valve, and the load cell provides an accurate indicator of the melt pressure at the gate. If the application results in shear stresses exceeding F2, the load cell can be pre-loaded to compensate for such stresses.

Similar to previous embodiments described above, the signal transmitted through cable 160 is compared by controller 151 with a target value of a target profile and the controller adjusts the position of the valve pin accordingly to increase or decrease flow rate. In this embodiment, the target profile is also a time versus pressure profile, but the pressure is the a result of the force of the pin on the load cell, as opposed to previous embodiments in which a pressure transducer directly senses the force of the flow of the melt material. The profile is created in similar fashion to the embodiments described above: running the process and adjusting the profile until acceptable parts are produced.

The valve pin controls the flow rate through the gate using a tapered edge 155 to form a control gap 153 close to the gate. It should be noted, however, that any of the other valve pin designs described herein can be used with the load cell 140. Accordingly, when the pressure sensed by the load cell is less than the target pressure on

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the target profile, the controller 151 signals the actuator to retract the valve pin to increase the size of the control gap 153 and, consequently, the flow rate. If the pressure sensed by the load cell 140 is greater than the target pressure, the controller 151 signals the actuator to displace the valve pin toward the gate to decrease the size of the control gap 153 and consequently, the flow rate.

The use of the load cell has an additional application shown in Figure 27A. In a single cavity multiple gate system it is often desirable to open gates in a cascading fashion as soon as the flow front of the melt material reaches the gate. When melt material 166 has flowed into the gate area of the valve pin, a force  $F_3$  from the melt in the cavity is exerted on the face 142 of the valve pin.

In this way, gates can be sequentially opened in cascading fashion by sensing the force of the melt pressure on the face of the valve pin when the valve pin is closed. Given typical gate diameters of .2 inches and melt pressures of 10,000 psi, the resulting force of 300 pounds is readily measured by available load sensors, since the force of the cell equals the area of the gate times the pressure at the gate. Thus, this melt detection can then be used to signal the opening of the gate as in the sequential valve gate. This assures that the gate does not open prematurely.

Figures 28A and 28B show an alternative embodiment in which the sheer stress on the valve pin is reduced. The nozzle 21 is designed to include a channel for melt flow 168 and a bore 170 through which the valve pin reciprocates. As such, the flow does not cause any axial sheer stress on the valve pin and thus reduces errors in pressure sensing. An indent 172 is provided in the nozzle 21 so that side load on the valve pin is reduced, i.e., to equalize pressure on both sides of the valve pin. An additional benefit to the configuration shown in Figures 28A and 28B is that since the flow of material is away from the valve pin, the valve pin does not "split" the flow of material, which can tend to cause part lines or a flow streak on the molded part.

Figure 29 shows another alternative embodiment of the present invention similar to Figure 19. As in Figure 19, a ram 565 is used to force material from well 640 into cavity 525 at a controlled rate. The rate is controlled by signals sent from controller 535 to servo valve 560A, which in turn controls the velocity at which actuator 560 moves ram 565 forward.

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In Figure 29, actuator 560 is shown in more detail including piston 564, actuator chamber 566, and hydraulic lines 561 and 562 controlled by servo valve 560A. Energizing hydraulic line 561 and filling chamber 566 causes piston 564 and ram 565 to move forward and displace material from well 640 through channel 585 and nozzle 520, and into cavity 525. In the embodiment of Figure 19, the controller controls the rate at which the ram injects material according to signals received by pressure transducer 530, compared to a target profile. In the embodiment of Figure 29, pressure transducer 530 has been removed in favor of pressure transducer 563 mounted along hydraulic line 561 which leads to chamber 566. The pressure transducer 560 senses the hydraulic fluid pressure in line 561 and sends a proportional signal to the controller 535. Since the pressure of the hydraulic fluid entering chamber 566 is directly related to the rate at which the ram 565 moves forward, and the rate at which the ram moves forward is directly related to the rate of material flow into the cavity 525, the pressure sensed by pressure transducer 560 is directly related to the rate of material flow into the cavity 525, and can be used to control the material flow rate.

Accordingly, as in previous embodiments, a target profile is created that has been demonstrated to generate acceptable molded parts. In the embodiment of Figure 29, however, the target profile represents target values of the hydraulic pressure sensed by pressure transducer 563, as opposed to directly sensing the material pressure. In operation, the controller compares the pressure signal sensed from pressure transducer 563 to the target pressure profile for gate 555. If the pressure sensed is too low, the controller will increase the hydraulic pressure in line 561 (which increases the velocity of the ram which increases flow rate of the material), if the pressure is too high the controller will decrease the hydraulic pressure (which decreases the velocity of the ram which decreases the rate of material flow).

The target pressure profile of the hydraulic fluid will appear similar to a conventional material profile, since the pressure of the hydraulic fluid will rise rapidly during the injection portion of the cycle, level off during the pack portion of the cycle, and go to zero pressure as cycle ends the valve pin 550 closes.

Although only one injection nozzle 520 and cavity 525 is shown, there is a like arrangement associated with each injection nozzle of actuators 575, 565, 545, as well as solenoid valves 540 and 570 and servo valve 560, to independently control the melt

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flowing from each gate, according to the target profile created for that gate. Also, although a single cavity 525 is shown, each nozzle may inject to multiple cavities or a single cavity mold. Only a single controller 535, however, is needed to control all the nozzles associated with manifold 515.

5           Using the foregoing arrangement of Figure 29, as in previous embodiments, the material flow from each nozzle of the manifold can be controlled independently.

Figure 30 shows another alternative embodiment of the present invention. The embodiment of Figure 30 is substantially the same as the embodiment shown in Figure 13 with the exception that pressure transducer 217 has been moved from manifold 231 to  
10           inside the mold half 650 which, together with mold half 660, forms mold cavity 670 in which the molded part is formed. Accordingly, in this embodiment, the target profile represents target values of the pressure sensed by pressure transducer 217 inside the cavity opposite the gate 211.

The operation of the embodiment of Figure 30 is the same as that described in the  
15           embodiment shown in Figure 13 in terms of target profile creation and use of valve pin 200 to control the material flow (interface 214 is not shown Figure 30 but can be used). However, placing the pressure transducer in the cavity offers several advantages, for example, in the cavity the pressure transducer 217 is not exposed to the high temperatures generated by the manifold, as in Figure 13. Also, the presence of the  
20           pressure transducer in the manifold may slightly disrupt material flow in the manifold. Another consideration in choosing whether to mount the transducer in the mold or in the manifold is whether the mold geometry permits the transducer to be mounted in the mold.

Figure 31 is another alternative embodiment of the present invention that is  
25           similar to Figure 13 (like reference characters are used wherever possible). Target profile creation as well as the flow control operation by valve pin 200 is substantially the same as described above. Figure 31, however, does not include a pressure transducer 217 as shown in Figure 13 to directly sense the flow of melt material into the cavity. Rather, similar to the embodiment shown in Figure 24, the arrangement shown in Figure  
30           31 performs flow control by sensing the material pressure F2 exerted by the melt material on the valve pin.

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In Figure 24 measuring the load on the valve pin was performed using a load cell 140, however, in Figure 31, it is performed by pressure transducers 700 and 710 mounted along hydraulic lines 720 and 730 which lead to actuator chambers 740 and 750, respectively. Energizing lines 720 and 730 and filling actuator chambers 740 and 750, enables axial movement of piston 223, thereby moving valve pin 200 and affecting the flow rate of the material into the cavity 760 as described above.

Pressure transducers 700 and 710 sense a differential pressure which is directly related to the force exerted on valve pin 200, which is directly related to the flow rate of the material. For example, when the material flow causes a force  $F_2$  to act on valve pin 200, the force relates up the valve pin to the piston, which in turn tends to increase the pressure in chamber 740 and line 720 and decrease the pressure in chamber 750 and line 730, directly causing a change in the difference in the pressures sensed by the transducers 700 and 710. Accordingly, the differential pressure is directly related to the flow rate of the material into the cavity.

Once an acceptable target profile of differential pressure is developed using techniques described above, the controller will cause the servo valve 212 to track this target profile by altering the position of the valve pin to change the flow rate of the material and track the differential pressure target profile. For example, if the differential pressure is too high (e.g., the pressure sensed by transducer 700 is higher than the pressure sensed by transducer 710 by an amount greater than the target differential pressure) the controller will cause servo valve to retract the valve pin to reduce the flow rate, thereby reducing the force  $F_2$  on the valve pin, thereby decreasing the pressure in chamber 740 and line 720, thereby decreasing the pressure sensed by transducer 700, thereby decreasing the difference in pressure sensed by transducers 700 and 710. Note, in certain applications the differential pressure may be negative due to the sheer force of the material on the valve pin, this however will not affect the controller's ability to track the target profile.

As in the embodiment shown in Figure 24, the embodiment shown in Figure 31 offers the advantage that it is not necessary to mount a pressure transducer in the mold or the manifold. As in all previous embodiments, the embodiment shown in Figure 31 enables the material flow from each nozzle attached to the manifold to be independently profileable.

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Figure 32 shows an entire control system arrangement 800 which can be used with any of the embodiments described above in Figures 1-31. In Figure 32, the system is shown with the manifold, nozzle and mold arrangement shown in Figure 1, and like reference characters are used wherever possible.

5 Similarly to Figure 1, the control system 800 includes a manifold 15 for dispensing material injected from machine nozzle 11 through injection molding nozzles 21 and 23 into a mold cavity 5. As explained above, each nozzle has a valve pin 41a and 41b associated therewith that is used to independently control the rate of material flow through nozzles 21 and 23 and into cavity 5. Servo valves 802 are controlled by  
10 controller 804 to in turn control actuators 49(a) and 49(b) to alter the respective positions of each valve pin according to a target pressure profile associated with that particular servo-valve, valve pin, injection nozzle, pressure transducer and gate (herein referred to as a "control zone"). As explained above, the valve pin of a control zone adjusts the flow rate of the material flowing to the gate of the control zone so that the pressure read  
15 by the pressure transducer in the control zone tracks the target values of pressure in the target profile for that control zone, throughout the injection cycle.

Real-time control is provided via feedback from pressure transducers 69(a) and 69(b) which record material pressure values, feed them back into controller 804, which compares the pressure values to target values throughout the injection cycle. The  
20 controller then displaces the valve pins, according to whether an increase or a decrease in material pressure is called for by the target profiles. According to one preferred embodiment, the target profiles are executed by, for example, a PID algorithm stored in the controller 804.

The controller 804 can include a programmable logic controller (PLC) to provide  
25 input/output connections. For example, the PLC can be used to capture the material pressure data from the pressure transducers 69(a) and 69(b), and also provide control signals to servo valves 802. The controller 804 is connected to both the servo valves 802 and the hydraulic power source 808 to monitor and control the hydraulic power source. The operator interface 805 is, for example, the same as interface 214 described with  
30 reference to Figures 14-18 above.

A complete control system 800 is shown in Figure 32 which includes an injection molding machine 806, which injects material into manifold 15 via nozzle 11. The

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machine includes a reciprocating screw 809 which is used to force material out of the injection molding machine fed from hopper 816. The screw is attached to a hydraulic actuator 818 which is controlled by the machine controller 812 which includes an operator interface 814. Pressurized hydraulic fluid is supplied to the actuator via an injection molding machine hydraulic power unit 810. Using the operator interface, a user can set injection time, injection pressure, pack pressure, pack time, etc., for any given injection cycle.

In addition to controlling the rate of material flow through each control zone, the controller 804 also interfaces with the injection molding machine in several ways. The controller 804 is coupled to the injection molding machine controller 812. The injection molding machine controller 812 can provide several different signals to the controller 804. For example, the controller 812 can indicate to the controller 804 that all gates and guards on the injection molding machine are closed and the machine 806 is in a state in which injection can occur. This signal should be received while the controller 804 is performing its controlling functions during the injection cycle.

The injection molding machine also can include an emergency stop button which could be wired to the controller 804 in which the controller 804 would not perform controlling operations if the emergency stop is indicated. The controller 812 also can provide a signal to the controller 804 to indicate the start of injection based on physical characteristics of the injection molding machine. This signal is to remain high until the end of injection and pack. Accordingly, the controller 804 can use this "start of injection" signal to begin control according to the target profiles. For example, the rising edge of the start of injection signal can indicate to the controller 804 that the start of injection has begun.

A start of injection signal can also be provided to controller 804 by a linear position transducer 820 indicating that the screw 809 is in a position in which injection has begun. Another way to provide a start of injection signal is to measure the pressure of the material in the machine nozzle 11 by a pressure transducer 820 coupled to controller 804. Basing the start of injection signal on these physical readings associated with the injection molding machine can insure that adequate pressure is being supplied to the manifold when the controller 804 begins executing the target profiles.

It is also desirable to provide an end of injection signal to the controller 804. One way to provide such a signal is to detect the falling edge of the injection molding machine "on" signal described above. The end of injection signal can also be indicated by the rising edge of an "injection molding machine injection complete" signal provided  
5 by controller 812. Lastly, the controller 804 itself can provide an end of injection signal, when all profiles have been completed. Thus, the end of injection signal is used to indicate to either the injection molding machine 806, the controller 804 or both, that the injection process is completed and all injection functionality should be discontinued.

The injection molding machine 812 can also provide a signal to the controller 804  
10 that the injection molding machine has transitioned from "injection pressure" to "pack pressure." According to one embodiment, controller 804 can use this signal to determine when the injection molding machine is transitioning and determine if said transitioning is prior to the target profiles transitioning to a pack pressure. This early transitioning of the injection molding machine can result in a cavity or cavities not filling entirely. Thus,  
15 controller 804 could use this signal to generate a warning message via operator interface 805 if early transitioning occurs.

The injection molding machine controller 812 can also provide a signal to the controller 804 that the injection molding machine has reached the end of its injection forward sequence (i.e., that the screw 809 has reached its forward-most position). The  
20 controller 804 could use this signal to alert an operator via operator interface 805 if the injection molding machine has stopped injecting before all of the target profiles have been completed. This signal can also be used to indicate that cycle times are not being minimized if the injection molding machine is still injecting after the controller 804 has completed all target profiles during the injection cycle.

25 The injection molding machine controller 812 may also provide a signal as to when the pre-decompression (when the screw 809 is reset prior to plastication), or decompression (when the screw 809 is reset after plastication), is complete. The signal can be used to indicate when the controller 804 can close valve pins 41(a) and 41(b) (i.e., withdraw the valve pins 41(a) and 41(b) until the manifold channels are closed) to be in  
30 position for the next injection cycle. If this signal is not provided, the controller will simply set a period of time from the end of the injection cycle to close the valve pins 41(a) and 41(b).



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The controller 804 also can communicate signals to the injection molding machine controller 812. The controller output interface 805 can also include an emergency stop as described above with respect to the injection molding machine. This emergency stop signal can be sent to the controller 812 and will act to halt the injection molding machine. The controller 804 can also provide a signal indicating to the controller 812 that the controller 804 is resident and must be interfaced with. The signal can be carried, for example, by a jumper cable connecting both controllers. The jumper will complete an input circuit with the injection molding machine indicating that the controller 804 is resident.

10       The controller 804 can also provide a "ready" signal to controller 812 indicating that the hydraulic power source 808 is ready and that no alarms are present that would inhibit injection.

      Controller 804 can also provide a signal to controller 812 indicating that all target profiles being executed by controller 804 have transitioned from the fill stage of injection to the pack and hold stage. In one embodiment, the injection molding machine uses the signal to unload the high volume pumps no longer necessary in the pack and hold stages. Another use of the signal is to trigger the start of gas injection for a gas assist application. The target profile of the injection cycle would end after injection of melt material after which gas is used to pack up the part.

20       The controller 804 can also provide a signal indicating that all the target profiles have been completed. The signal can then be used to abort the injection molding machine cycle and thus reduce wasted cycle time. This signal can also be used to indicate that cycle times are not being minimized if the injection molding machine is still injecting after the target profiles are completed. Accordingly, this information could be used to reset the injection molding machine cycle time. Controller 804 can also provide a signal to the injection molding machine indicating that there was a control problem during the injection cycle and therefore a high likelihood that the parts could be faulty.

      The system 800 also includes cavity pressure transducers 824 and 826. These transducers provide useful information related to the molding process. The transducers can be used to monitor and display cavity pressure via pressure profile curves for each control zone. This information can be used for trouble shooting to determine if any process changes have occurred. The information can also be used for statistical process

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control to ensure that the process stays within determined operating limits. For example, pressure readings from these pressure transducers can establish acceptance criteria for peak pressure, pack pressure, average pressure, area under the pressure curve, or other pressure values during the injection cycle. Parts created during a cycle in which these  
5 criteria were not met can be rejected, or at least a notification can be generated at the operator interface 805 to warn the operator.

The use of cavity transducers 824 or 826 provides greater control of the process. For example, if one of the transducers consistently registers too high or too low a pressure at a particular point in the injection cycle, the target profile associated with that  
10 control zone can be altered accordingly, using operator interface 805. This can be especially useful in a large part having multiple gates. Placing cavity transducers at multiple points along the cavity provides information on how the part fills during the process and, if the part is not filling properly, on which target profiles of which control zones should be altered and how they should be altered.

15 Transducers 824 and 826 can also be used to trigger switchover in the target profiles (and/or the injection molding machine) from injection pressure to pack pressure. In the embodiments described above switchover from injection pressure to pack pressure is determined by the target profiles according to time, however, using the pressure transducers, a set point pressure can be established at which time the target profile  
20 switches to the "pack" area of the profile, independent of time. This can be done for each target profile separately, as there would be a cavity pressure transducer associated with each control zone. This variable can also be used to control when the injection molding machine switches from injection pressure to pack pressure.

Switchover can also be controlled by placing transducers at either end of cavity 5.  
25 When the pressure transducers detect material pressure at the end of the cavity, the controller 804 can switch the control zone (or zones) associated with that end of the cavity to the "pack" portion of the target profile. This method of controlling "switchover" can account for variations in material viscosity which can cause the part to fill more quickly or slowly, thus, making a time-based "switchover" inexact.

30 Controlling "switchover" is also useful in multiple cavity applications, as shown in Figure 35. In a mold have multiple like cavities 5a and 5b, ideally the controller 804 would "switchover" each control zone (one for each cavity when each cavity has a single

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gate) from injection to pack at the same point in time during the injection cycle. Material and flow variations in the multiple cavities, however, may cause the filling rates to be slightly different from one cavity to the next. Using a pressure transducer in each cavity 5a and 5b to trigger switchover independently for each control zone, as described above, 5 compensates for these variations and can improve the repeatability of the process. Alternatively, the cavity pressure transducer can be used to "tweak" each target profile to create uniform cavity pressure readings (and uniform parts) from each cavity. In the multi-cavity application the pressure transducer can be located adjacent the gate similarly to Figure 32, or at an end of each cavity 5a and 5b as shown. As described above, either 10 location can be used to control switchover.

The cavity pressure transducers can also be used to determine the end of the pack period, unlike previous embodiments in which the profile itself dictates the end of pack at a particular time after the start of injection. Again referring to Figure 35, transducers located at the end of the cavities 5a and 5b, can be used to determine the end of the pack 15 period for individual cavities (or a single cavity) by indicating when the pressure at the end of the cavity reaches a particular value during pack indicating that the part is filled. Thus, the end of pack can be independently set in each control zone according to when a particular pressure is detected. If an extended valve pin is used (see Figures 11-15), the valve pins can be closed according to this pressure-based end of pack determination. 20 The use of pressure to determine end of pack ensures consistent part weight by compensating for flow variations within the cavity or cavities which may change from shot to shot.

For cascade molding, cavity pressure transducers can be used to indicate the arrival of the material flow front at a gate downstream of the initial gate opened. Once 25 the flow front is past the downstream gate, the cavity pressure transducer will see a rise in pressure. The controller 804 can then start the injection at the next gate based on a determined pressure set point measured by the cavity pressure transducer.

As shown in Figure 32, the controller 804 also interfaces with machine nozzle pressure transducer 822. As explained above, this pressure can be used by the controller 30 804 to start the target profiles, and also be used to ensure that the supply pressure is high enough to run the process. If the injection molding machine 806 is supplying an

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inadequate pressure, a signal could be generated by the controller 804 and displayed on the operator interface 805.

The controller also interfaces with a linear transducer 820 that measures the position of the ram 809 and can be used as an indicator of the volume of material  
5 injected into the part. "Switchover" from injection pressure to pack pressure in both the target profiles and the injection molding machine (described above) can also be based on a set point value associated with linear transducer 820 indicating that the proper volume of material has been injected into the mold.

Figure 33 shows an alternative embodiment similar to the system shown in  
10 Figure 32. In this embodiment, however, the hydraulic power source 808 has been eliminated and servo valves 802 are connected directly to the injection molding machine hydraulic power unit 810. Thus, hydraulic power to servo valves 802 used to manage the flow of pressurized fluid to actuators 49(a) and 49(b) comes directly off the injection molding machine power unit 810, and this configuration saves the expense of having a  
15 separate power source 808 to supply servo valves 802. The system is the same as the system shown in Figure 32 in all other respects.

Several other alternative configurations are possible with respect to Figure 33. For example, an accumulator (not shown) can also be connected to the hydraulic power unit 810 to ensure a steady supply of pressurized fluid to servo valves 802 of which there  
20 is a single servo valve for each actuator 49(a) and 49(b). Also, the servo valve 802 may be mounted to the injection molding machine directly or to the mold as shown.

Figure 34 shows another alternative embodiment of a injection molding system similar to the system shown in Figure 33. In Figure 34, however, the controller 804 and operator interface 805 has been integrated as part of the injection molding machine  
25 controller 830 and 832. Controller 830 and operator interface 832 perform the functions of controllers 804, 812, and operator interfaces 805 and 814 of Figures 32 and 33. This integration simplifies the system and reduces the hardware in the system.

The integration can be performed by simply mounting the programmable controller described above within controller 804 into the injection molding machine  
30 control cabinet which contains controller 812. In such a case the input and output functions performed by controller 804 would still be performed by the same PLC. Alternatively, a single PLC or other type of controller can be used to interface all

injection molding machine controller functions and functions performed by controller 804. The operator interface 832 performs the functions of both operator interfaces 805 and 814 of Figures 32 and 33 and interfaces directly with the PLC that controls servo valves 802 for menus, set-up displays of process readings, and other functions.

5           The hydraulics in Figure 34 are the same as in Figure 33 with servo valves 802 being supplied hydraulic power by injection molding machine hydraulic power unit 810. Alternatively, separate hydraulic power sources can be used as shown in Figure 32.

          Having thus described certain embodiments of the present invention, various alterations, modifications, and improvements will readily occur to those skilled in the art.  
10       Such alterations, modifications, and improvements are intended to be within the spirit and scope of the invention. For example, in the embodiments shown in Figures 31-33, although only two gates are shown to a single cavity 5, more gates (and associated nozzles, valve pins, actuators and servo valves, i.e., control zones) may be used which gate into one or more cavities.

15           Additionally, servo valves 802 are shown in Figures 32-35 (and previous embodiments), however, the invention is not so limited and other types of valves such as proportional valves may be used. Also, although hydraulic actuators 49a and 49b are used in Figures 32-35 (and previous embodiments), pneumatic or electronic actuators can be used to control the valve pins (for example, the electronic actuators disclosed in  
20       co-pending patent application serial number 09/187,974 entitled ELECTRONIC ACTUATOR FOR PIN). Thus, the invention is not limited to a particular type of actuator. Further still, although a hydraulic-powered injection molding machine is shown in Figures 32-35, the invention is not limited to a particular type of injection molding machine. For example, an electronic injection molding machine could be used.

25           Accordingly, the foregoing description is by way of example only, and not intended to be limiting. The invention is limited only as defined in the following claims and the equivalents thereof.

CLAIMS

1. An injection molding system comprising:  
an injection molding machine including a hydraulic power source;  
5 a manifold for distributing material injected from said injection molding machine  
to a plurality of gates leading to one or more mold cavities; and  
a controller to individually control respective rates at which material is injected  
through said gates during an injection cycle, wherein the controller is coupled to the  
hydraulic power source and the hydraulic power source supplies hydraulic power to both  
10 the injection molding machine and to control said respective rates.
2. The injection molding system of claim 1, further comprising a plurality of  
actuators respectively associated with said plurality of gates, wherein said hydraulic  
power source supplies hydraulic power to said plurality of actuators.  
15
3. The injection molding system of claim 2, further comprising a plurality of  
valve pins, wherein each actuator is coupled to one of said valve pins to axially displace  
said valve pins to alter a rate of material flow through a gate associated therewith.
- 20 4. The injection molding system of claim 4, further comprising a plurality of  
servo valves coupled to said hydraulic power source, wherein said servo valves are  
controlled by said controller to regulate the flow of hydraulic fluid to said actuators.
5. An injection molding system comprising:  
25 an injection molding machine; and  
a manifold for distributing material injected from said injection molding machine  
to a plurality of gates leading to one or more mold cavities, wherein the injection  
molding machine includes a controller to individually control respective rates at which  
material is injected through said gates during an injection cycle.  
30
6. The injection molding system of claim 5, wherein the injection molding  
machine also includes a controller to control a rate at which the injection molding  
machine injects material into said manifold.

7. The injection molding system of claim 6, wherein a same controller is used to individually control respective rates at which material is injected through said gates during an injection cycle and to control a rate at which the injection molding machine injects material into said manifold.

8. The injection molding system of claim 5, wherein the controller controls the respective rates within the manifold.

9. The injection molding system of claim 5, wherein the controller controls the respective rates within individual injection nozzles coupled to the manifold that each lead to a gate.

10. The injection molding system of claim 6, wherein the injection molding machine further comprises an operator interface used to set parameters related to the respective rates at which material is injected through said gates during an injection cycle and the rate at which the injection molding machine injects material into said manifold.

11. An injection molding system comprising:  
an injection molding machine;  
a manifold for distributing material injected from plurality of a nozzles of said injection molding machine to a plurality of gates leading to one or more mold cavities;  
a controller to individually control respective rates at which material is injected through said gates during an injection cycle; and  
a pressure transducer coupled to the nozzle of said injection molding machine, wherein said controller receives pressure data from said pressure transducer.

12. The injection molding system of claim 11, wherein the controller uses said pressure data to determine when the injection molding machine has started injection.

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13. The injection molding system of claim 11, wherein the controller controls each respective rate based on a sensed condition related to the rate of material flow through the gate associated therewith.

5 14. The injection molding system of claim 13, wherein the controller controls each respective rate based on target profile of said sensed condition associated with each gate.

15. An injection molding system comprising:  
10 an injection molding machine;  
a manifold for distributing material injected from a plurality of nozzles of said injection molding machine to a plurality of gates leading to one or more mold cavities;  
a controller to individually control respective rates at which material is injected through said gates during an injection cycle; and  
15 a position transducer coupled to a screw of said injection molding machine, wherein said controller receives position data of said screw from said position transducer.

16. The injection molding system of claim 15, wherein the controller uses  
20 said position data to determine when the injection molding machine has started injection.

17. The injection molding system of claim 15, wherein the controller uses said position data to determine when to switchover each respective rate from injection to pack.  
25

18. The injection molding system of claim 15, wherein the controller controls each respective rate based on a sensed condition related to the rate of material flow through the gate associated therewith.

30 19. The injection molding system of claim 18, wherein the controller controls each respective rate based on target profile of said sensed condition associated with each gate.



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20. An injection molding system comprising:  
an injection molding machine;  
a hot runner including a manifold and a plurality of injection nozzles for  
5 distributing material injected from said injection molding machine to a plurality of gates  
leading to one or more mold cavities;  
a controller to individually control respective rates at which material is injected  
through said gates during an injection cycle; and  
at least one pressure transducer mounted in the one or more cavities, the pressure  
10 transducer coupled to the controller to send pressure data to the controller, wherein the  
controller alters the at least one respective rate from an injection pressure to a pack  
pressure when the pressure transducer detects a predetermined pressure value.
21. The injection molding system of claim 20, wherein control of each rate is  
15 based on a sensed condition related to the rate of material flow through each gate, each  
sensed condition being sensed at location in said hot runner.
22. The injection molding system of claim 20, wherein the at least one  
pressure transducer is a plurality of pressure transducers each respectively associated  
20 with one of said plurality of gates.
23. The injection molding system of claim 22, wherein each pressure  
transducer is located adjacent to the gate associated therewith.
24. The injection molding system of claim 22, wherein said one or more  
25 cavities is a plurality of cavities, and each pressure transducer is located adjacent an end  
of one of said plurality of cavities.
25. The injection molding system of claim 21, further comprising a plurality  
30 of pressure transducers coupled to said hot runner for sensing said sensed conditions,  
each pressure transducer being associated with one of said gates.

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26. The injection molding system of claim 25, wherein each pressure transducer is coupled to one of said plurality of injection nozzles.

27. The injection molding system of claim 25, wherein each pressure  
5 transducer is coupled to the manifold.

28. An injection molding system comprising:  
an injection molding machine;  
a hot runner including a manifold and a plurality of injection nozzles for  
10 distributing material injected from said injection molding machine to a plurality of gates  
leading to one or more mold cavities;  
a controller to individually control respective rates at which material is injected  
through said gates during an injection cycle; and  
at least one pressure transducer mounted in the one or more cavities, the pressure  
15 transducer coupled to the controller to send pressure data to the controller, wherein the  
controller determines an end of the pack period of the injection cycle for at least one  
respective rate when the pressure transducer detects a predetermined pressure value.

29. The injection molding system of claim 28, wherein the at least one  
20 pressure transducer is a plurality of pressure transducers each respectively associated  
with one of said plurality of gates.

30. The injection molding system of claim 29, wherein said one or more  
cavities is a plurality of cavities, and each pressure transducer is located adjacent an end  
25 of one of said plurality of cavities.

31. An injection molding system comprising:  
an injection molding machine;  
a hot runner including a manifold and a plurality of injection nozzles for  
30 distributing material injected from said injection molding machine to a plurality of gates  
leading to one or more mold cavities;

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a plurality of pressure transducers coupled to said hot runner for sensing material pressure flowing to said gates; and

at least one pressure transducer mounted in the one or more cavities, the pressure transducer to sense the material pressure inside the one or more cavities.

5

32. The injection molding system of claim 31, wherein each of said plurality of pressure transducers is coupled to one said plurality of injection nozzles.

33. The injection molding system of claim 31, wherein each of said plurality  
10 of pressure transducers is coupled to a channel of the manifold leading to one of said gates.

34. The injection molding system of claim 31, further comprising a controller  
to which the plurality of pressure transducers and the at least one pressure transducer are  
15 coupled, the controller controlling a rate of material flow through each gate based on pressure readings from the plurality of pressure transducers and the at least one pressure transducer.

20

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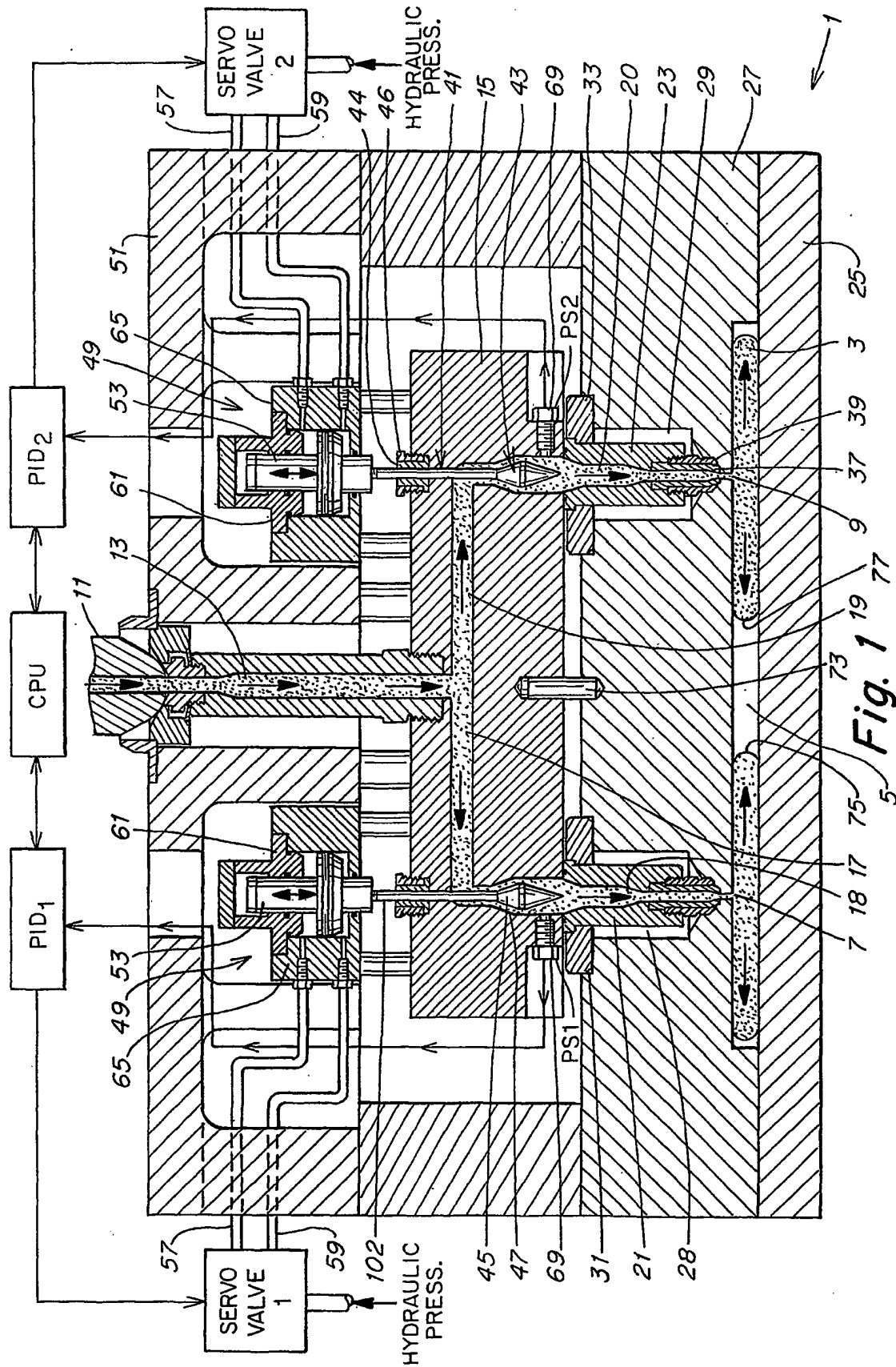
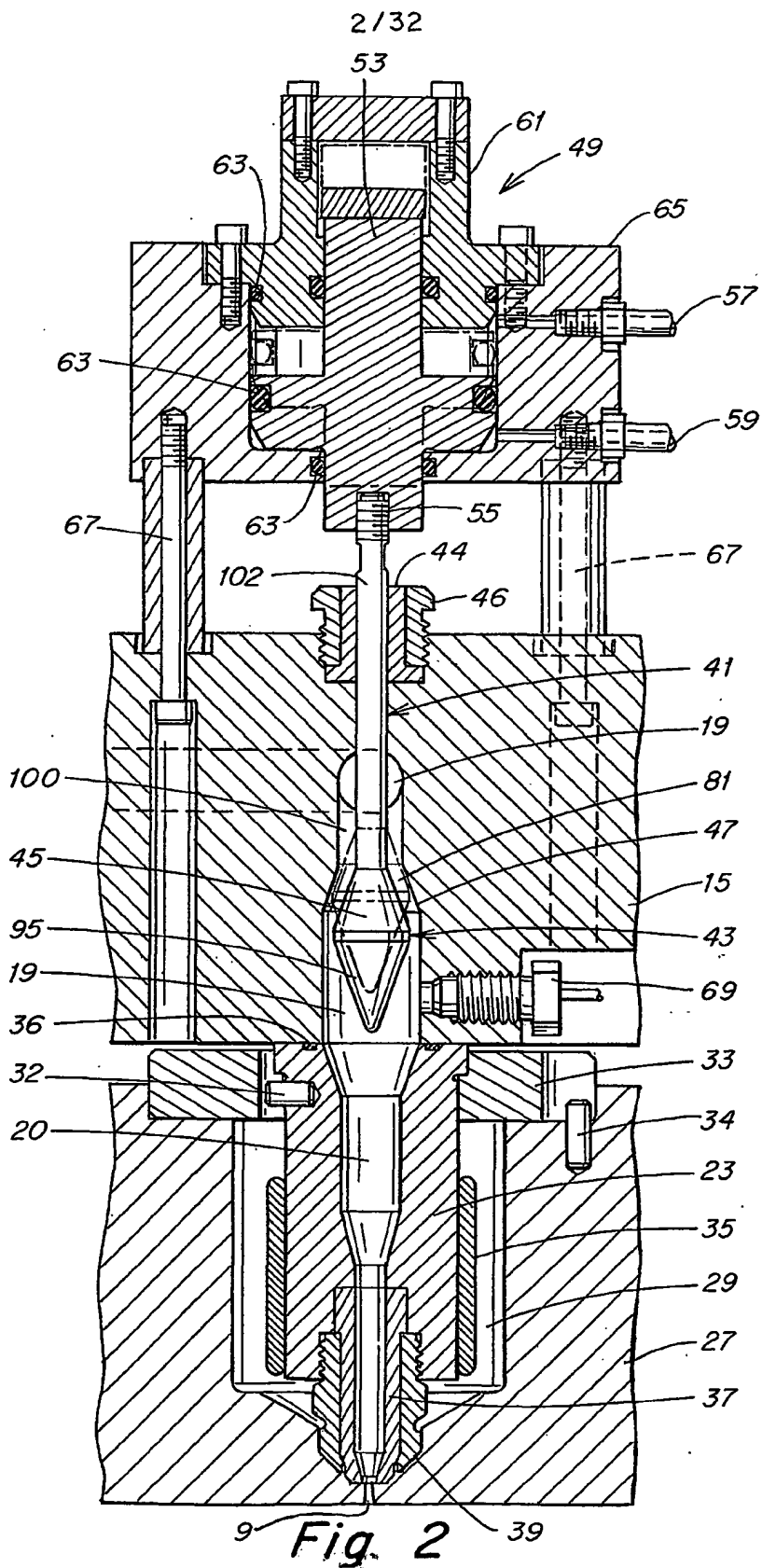
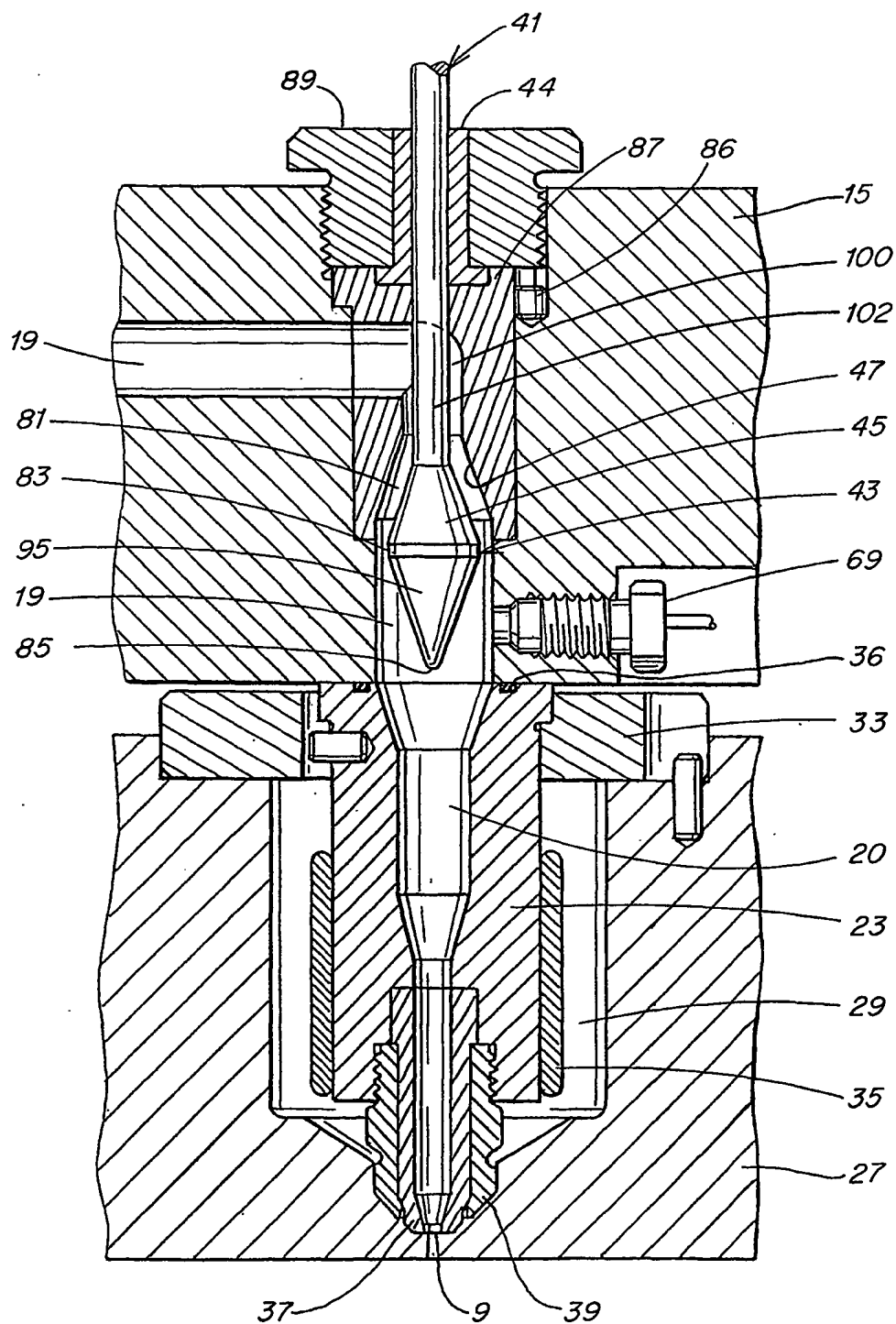
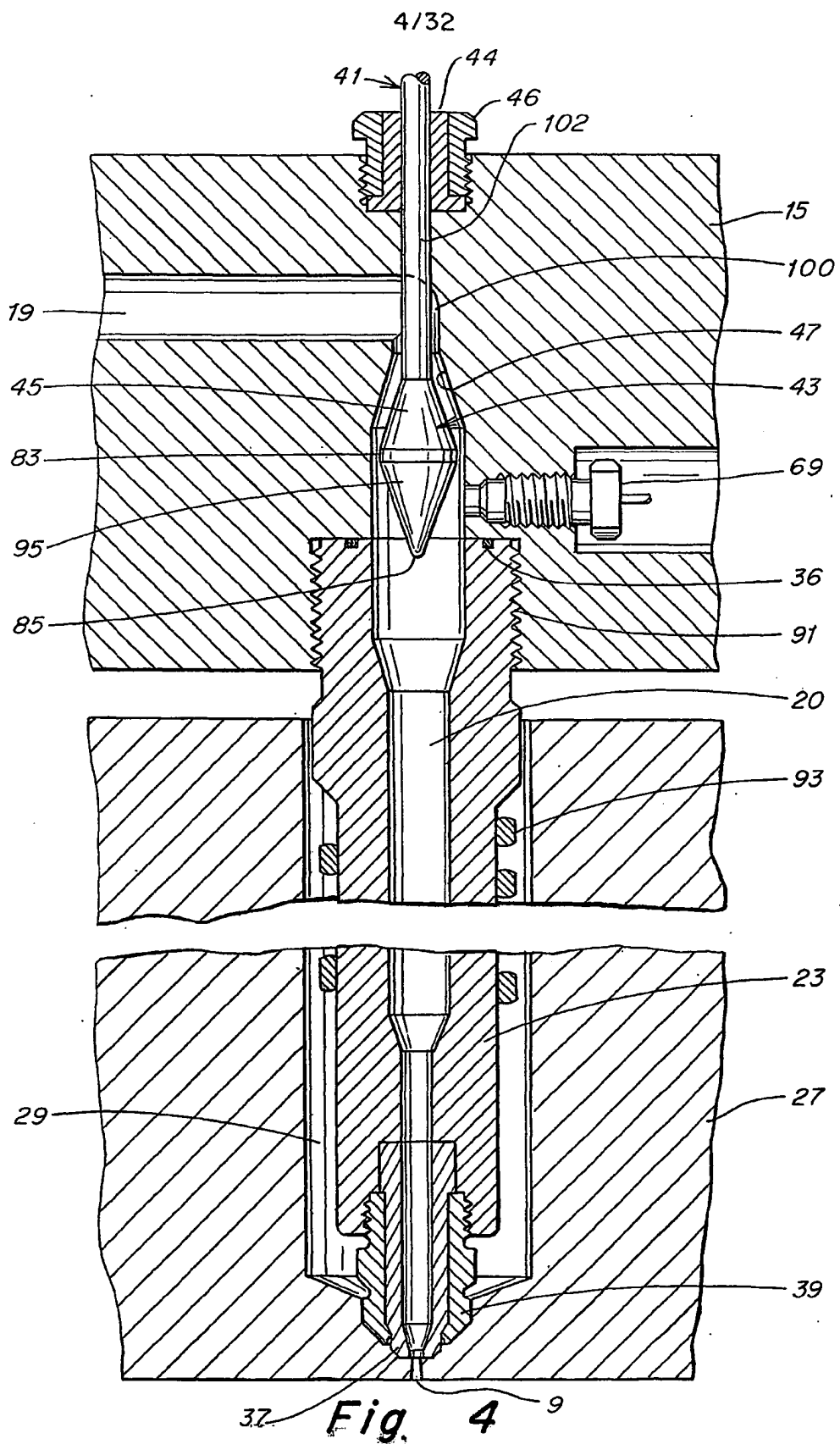


Fig. 1



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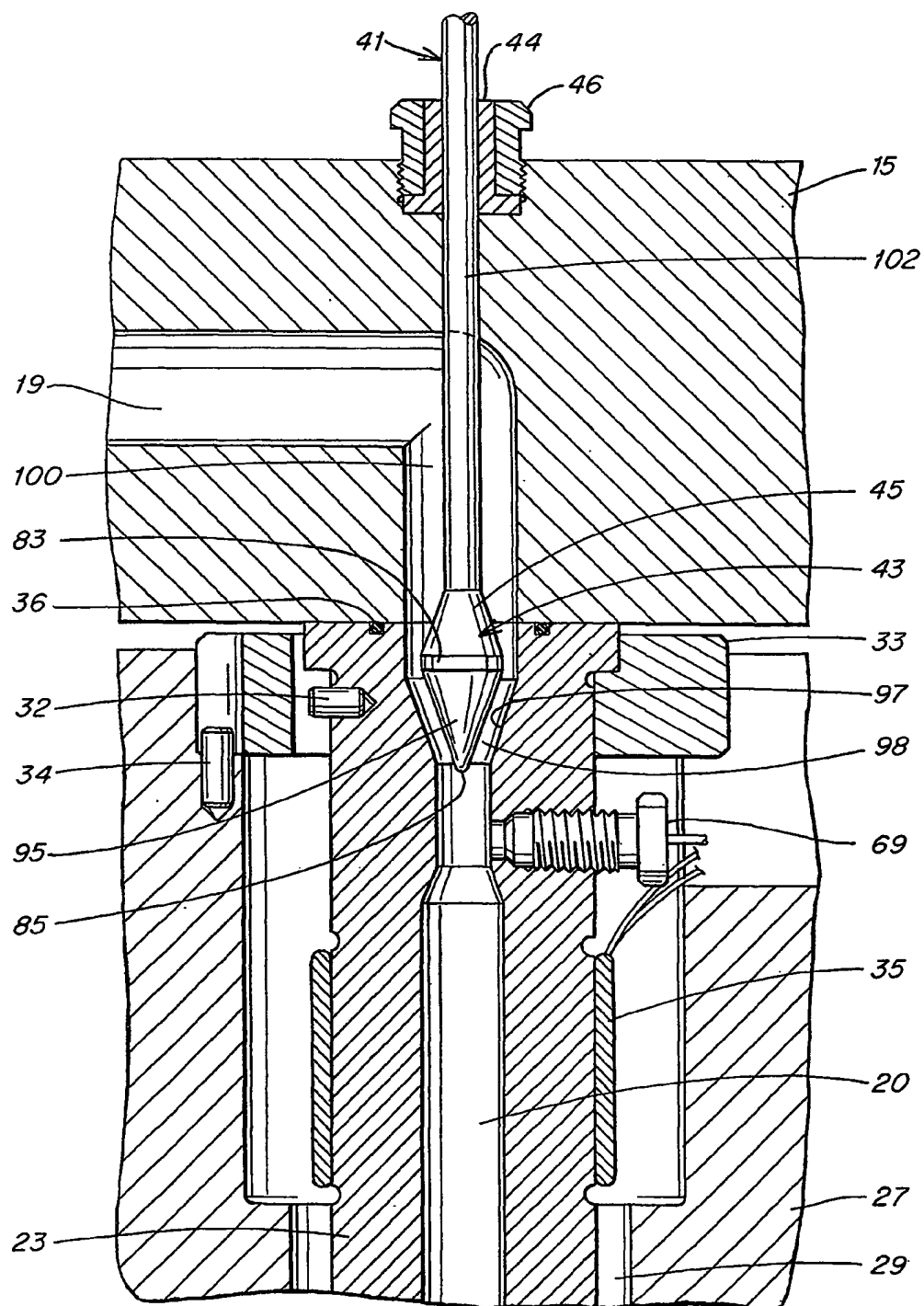
**Fig. 3**



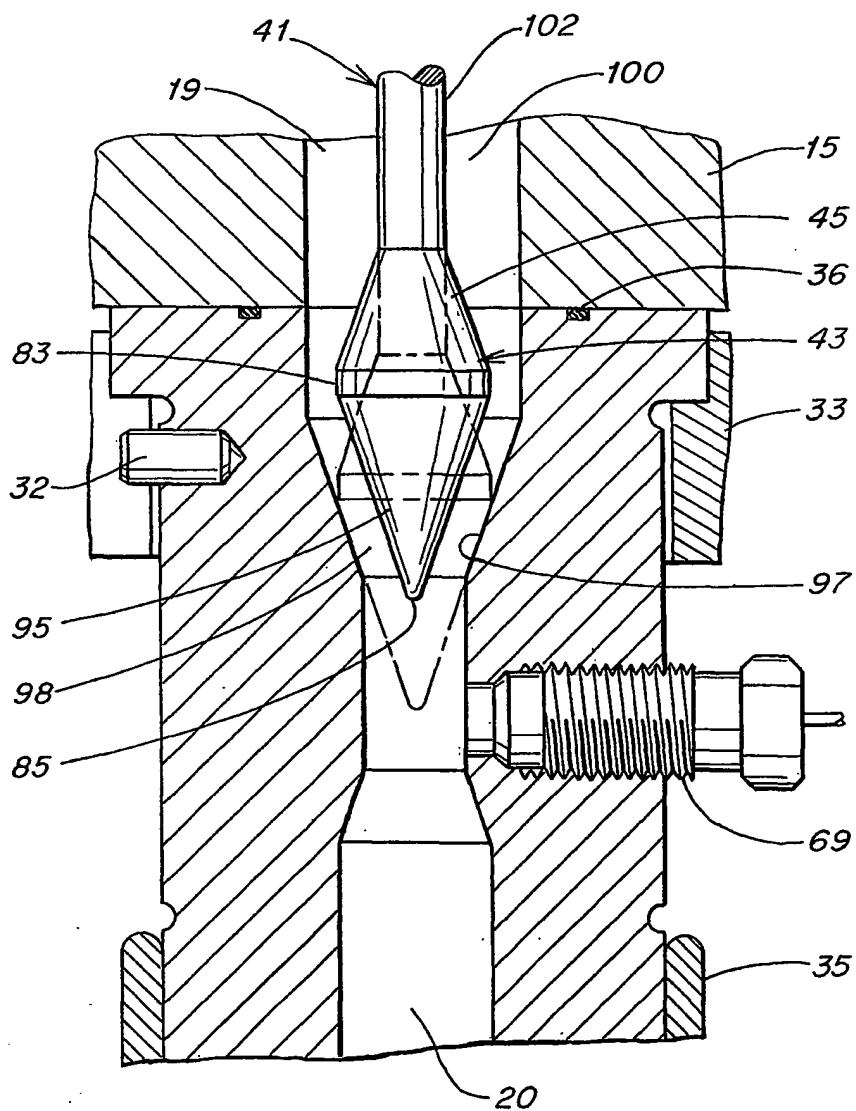


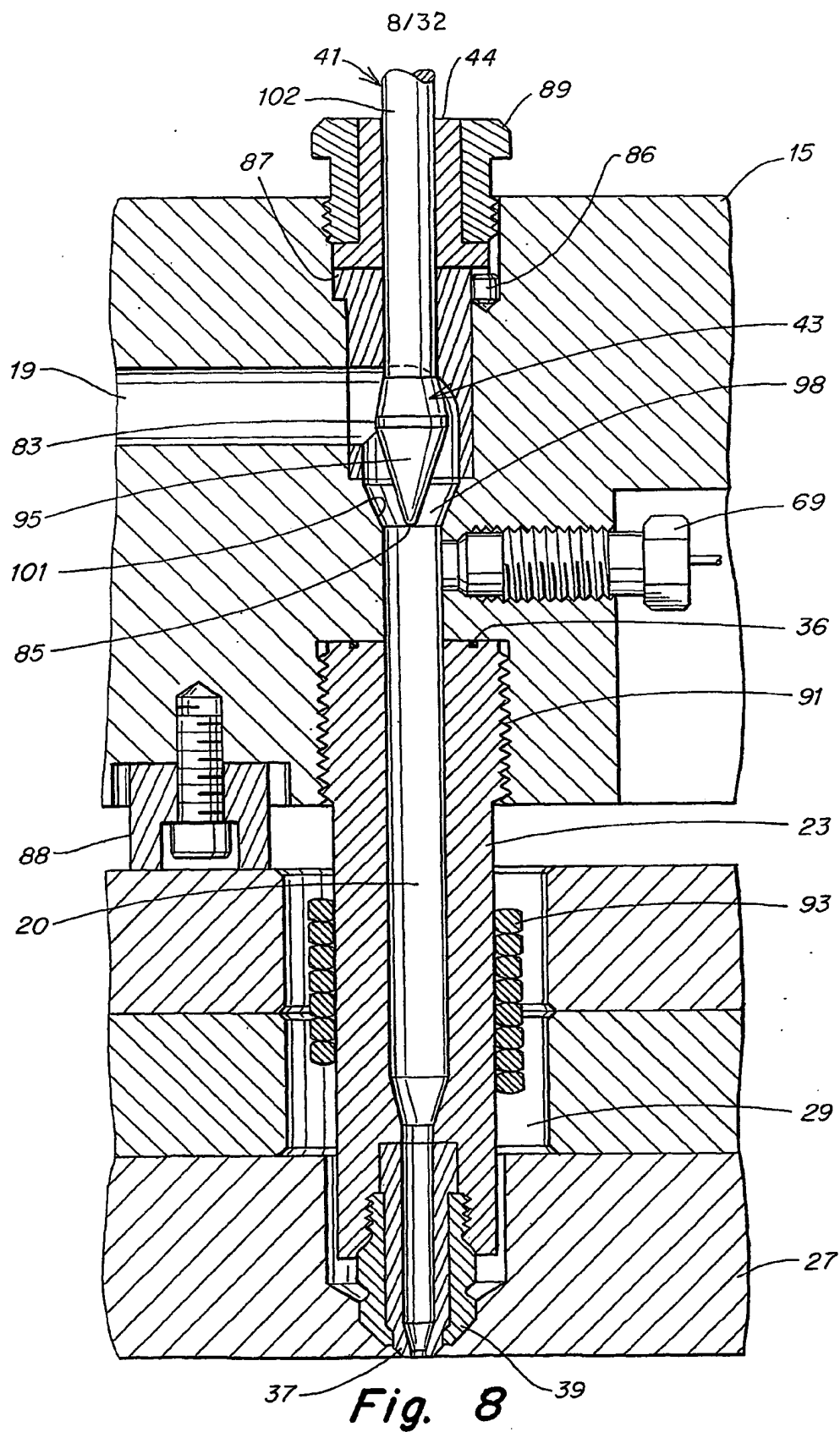


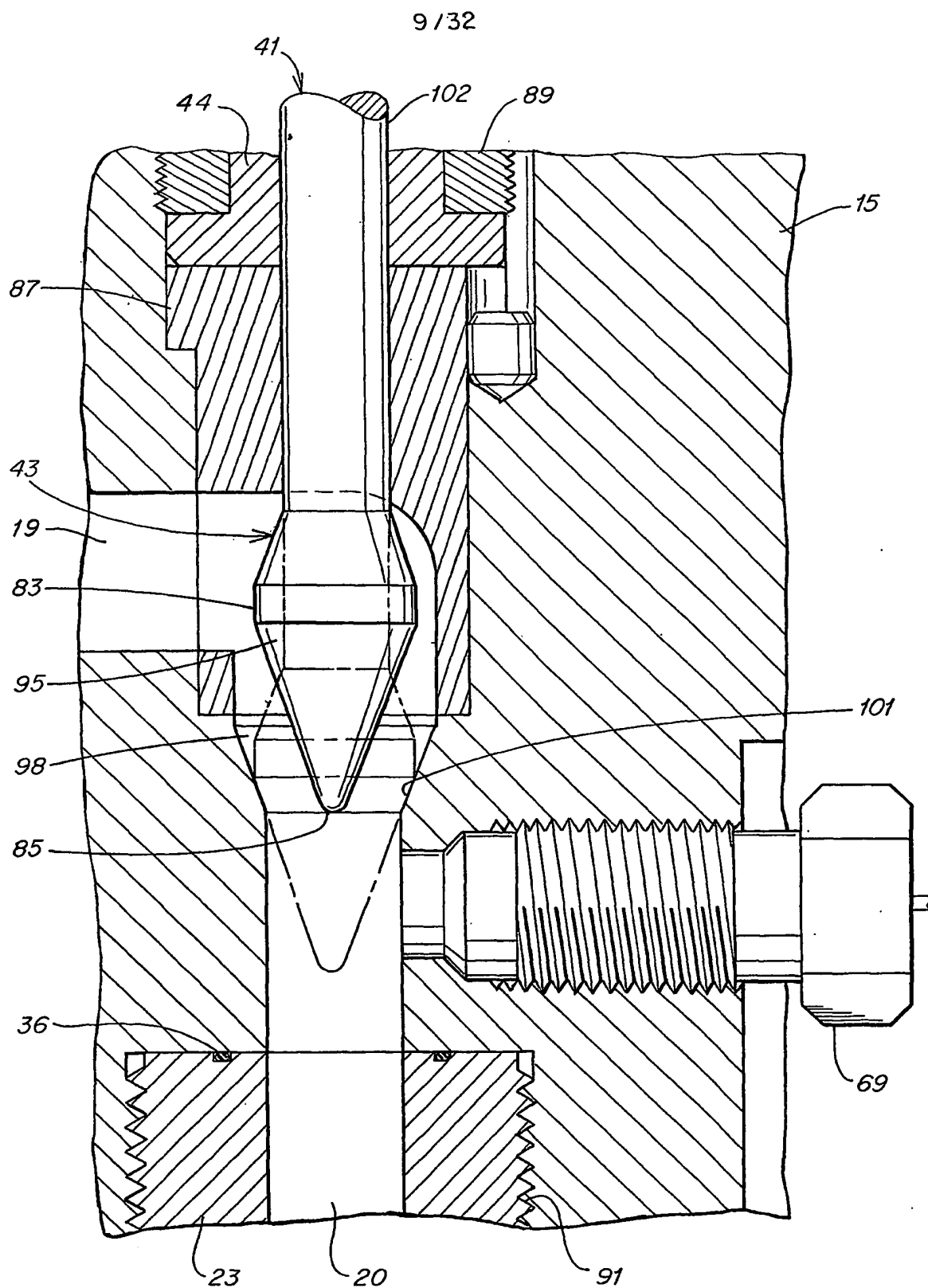
6/32

*Fig 6*

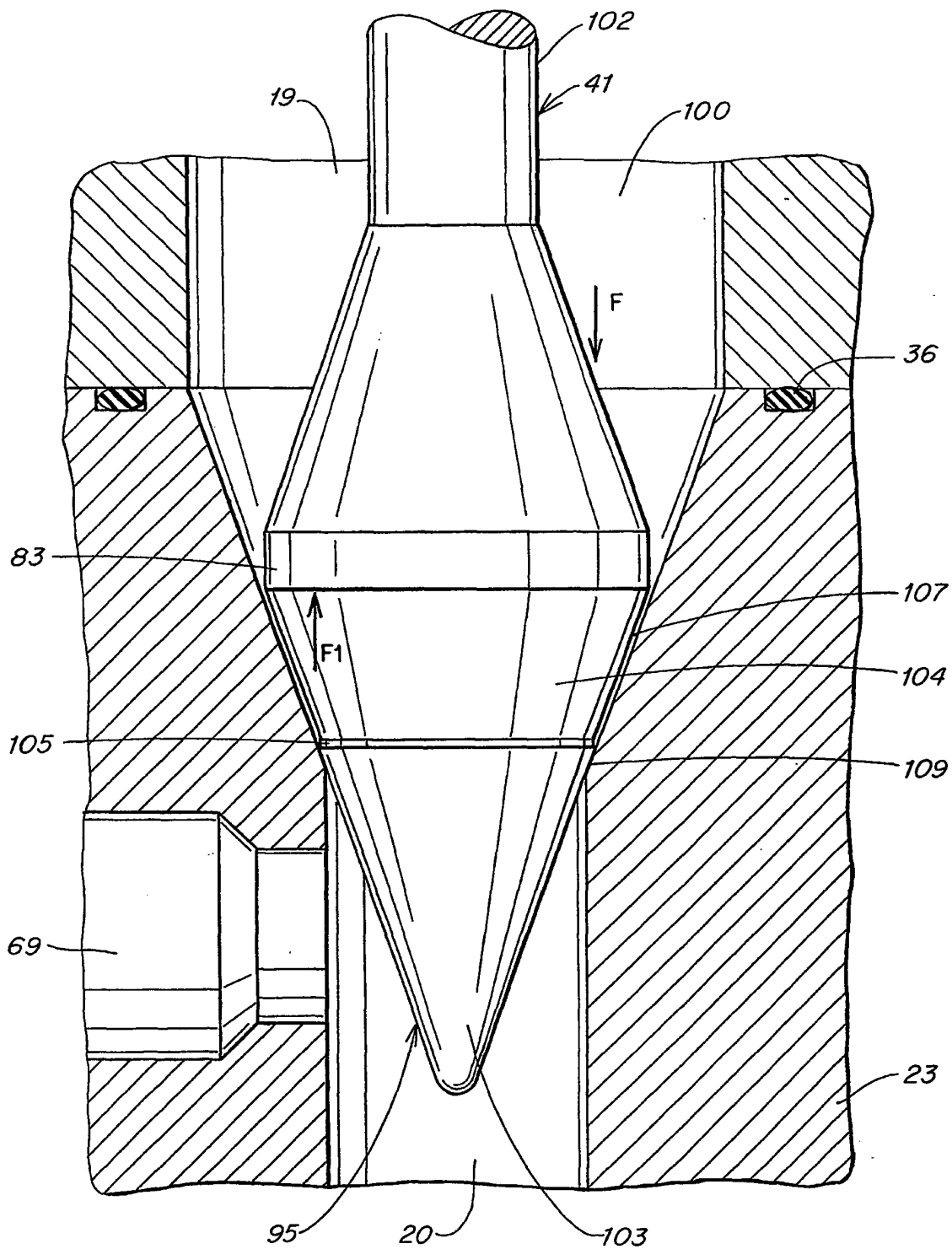
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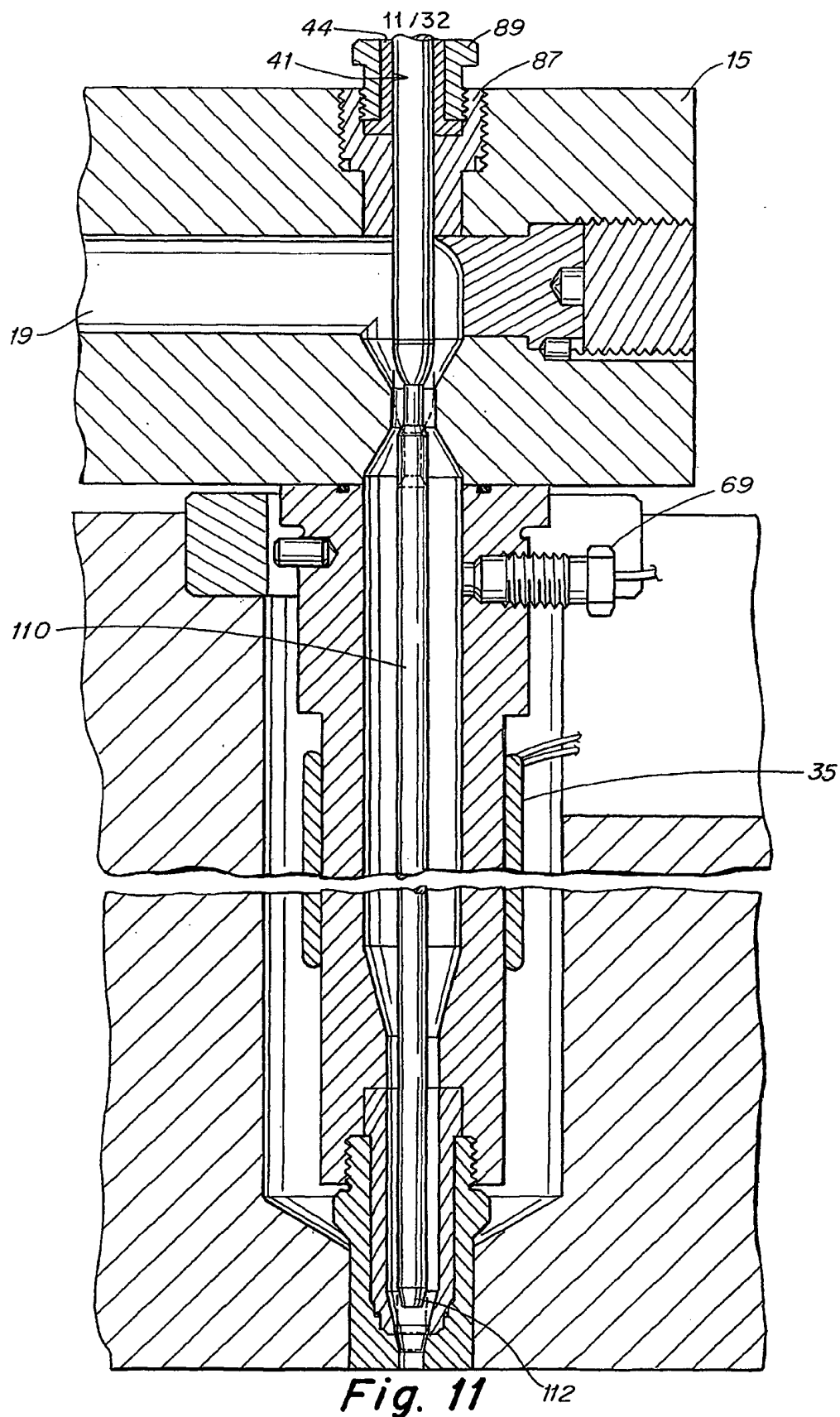
*Fig. 7*

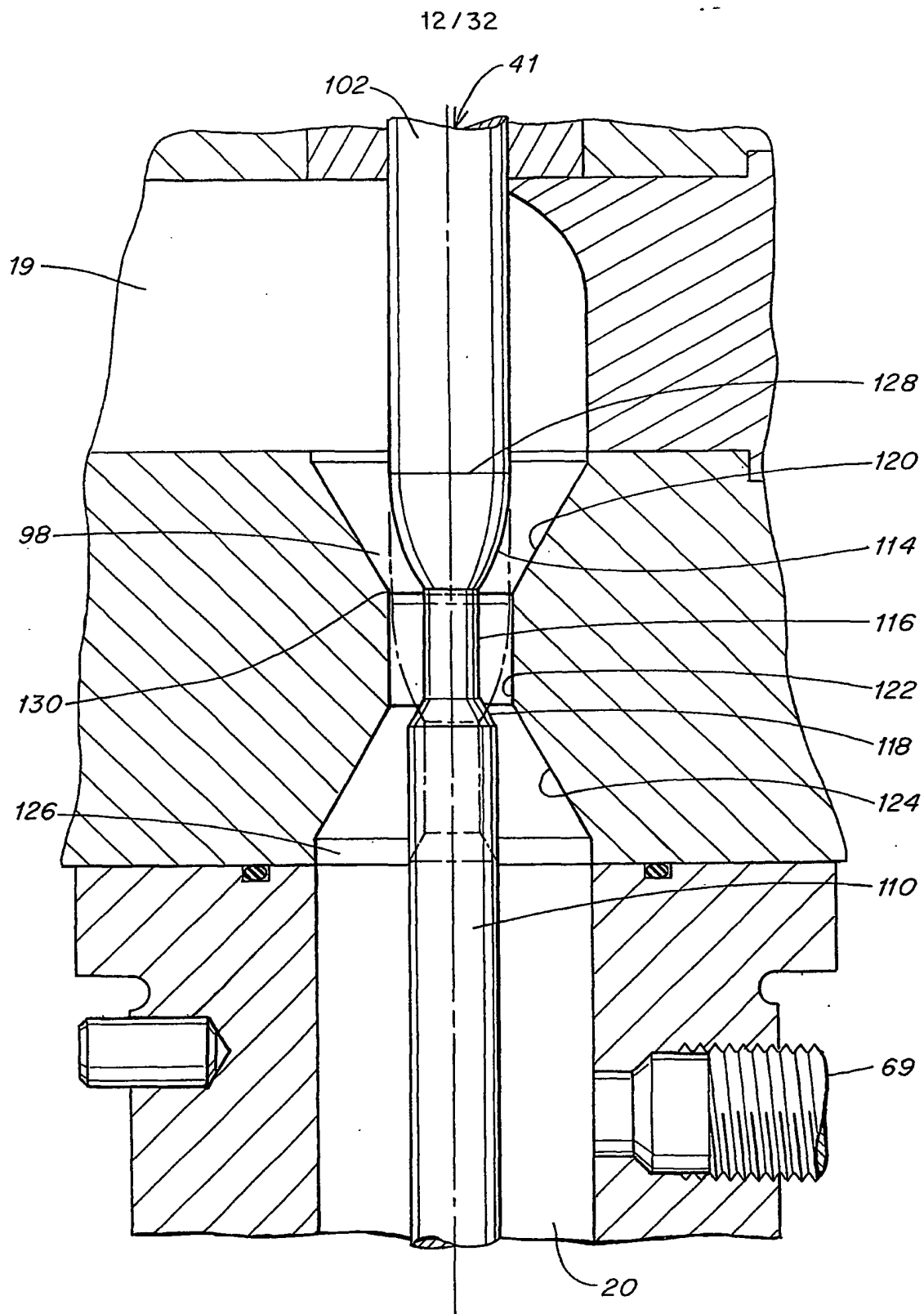


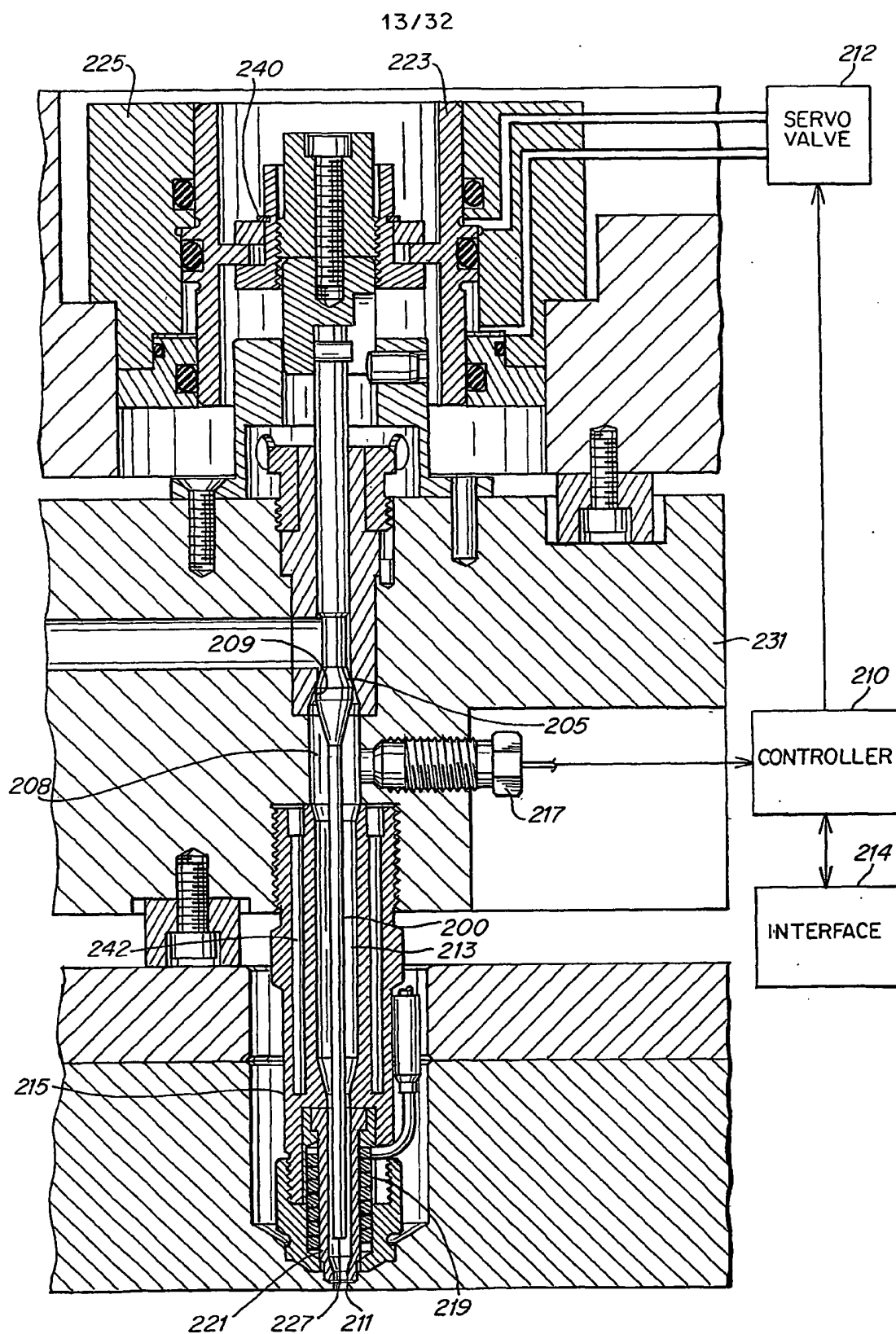
**Fig. 9**

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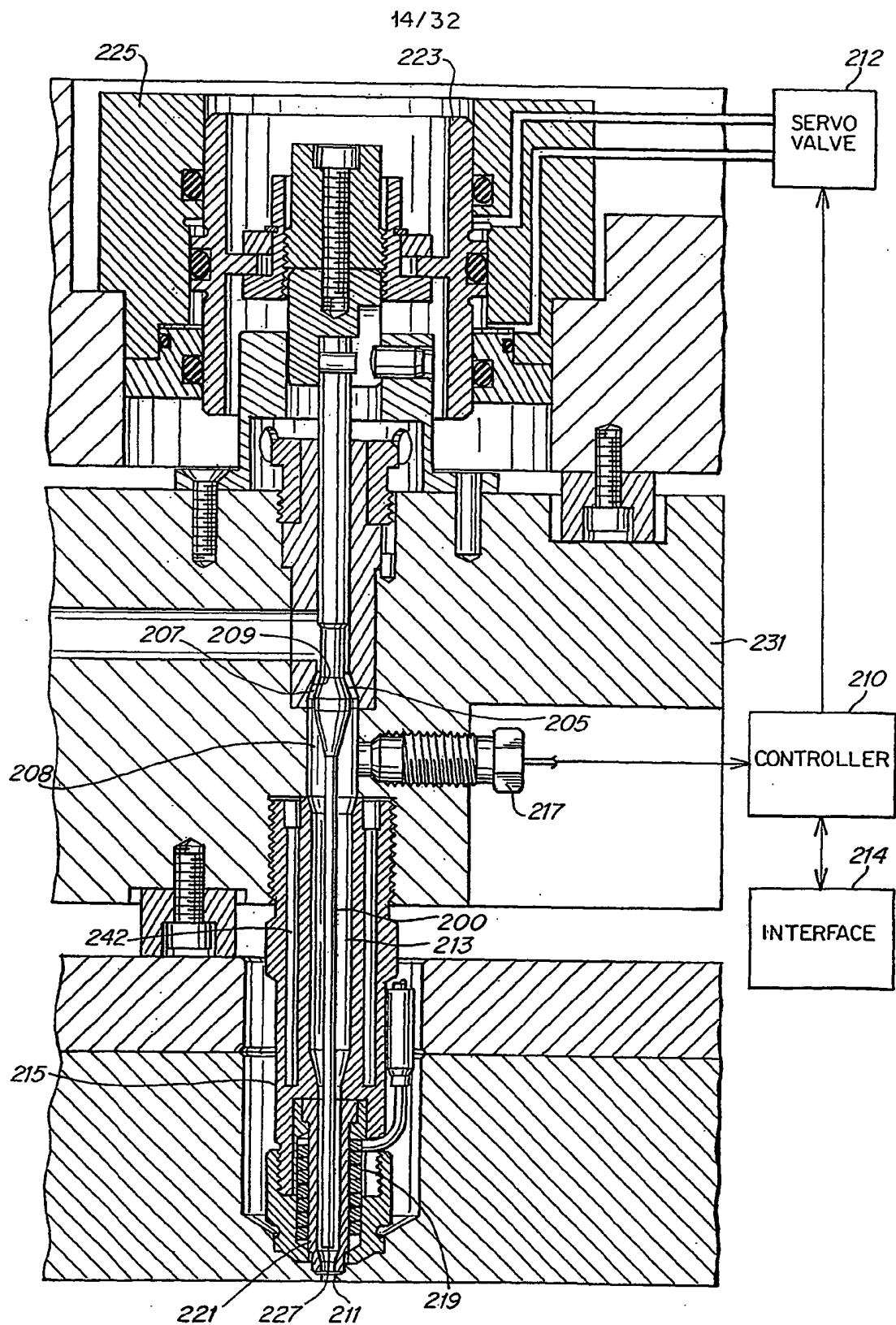
**Fig. 10**

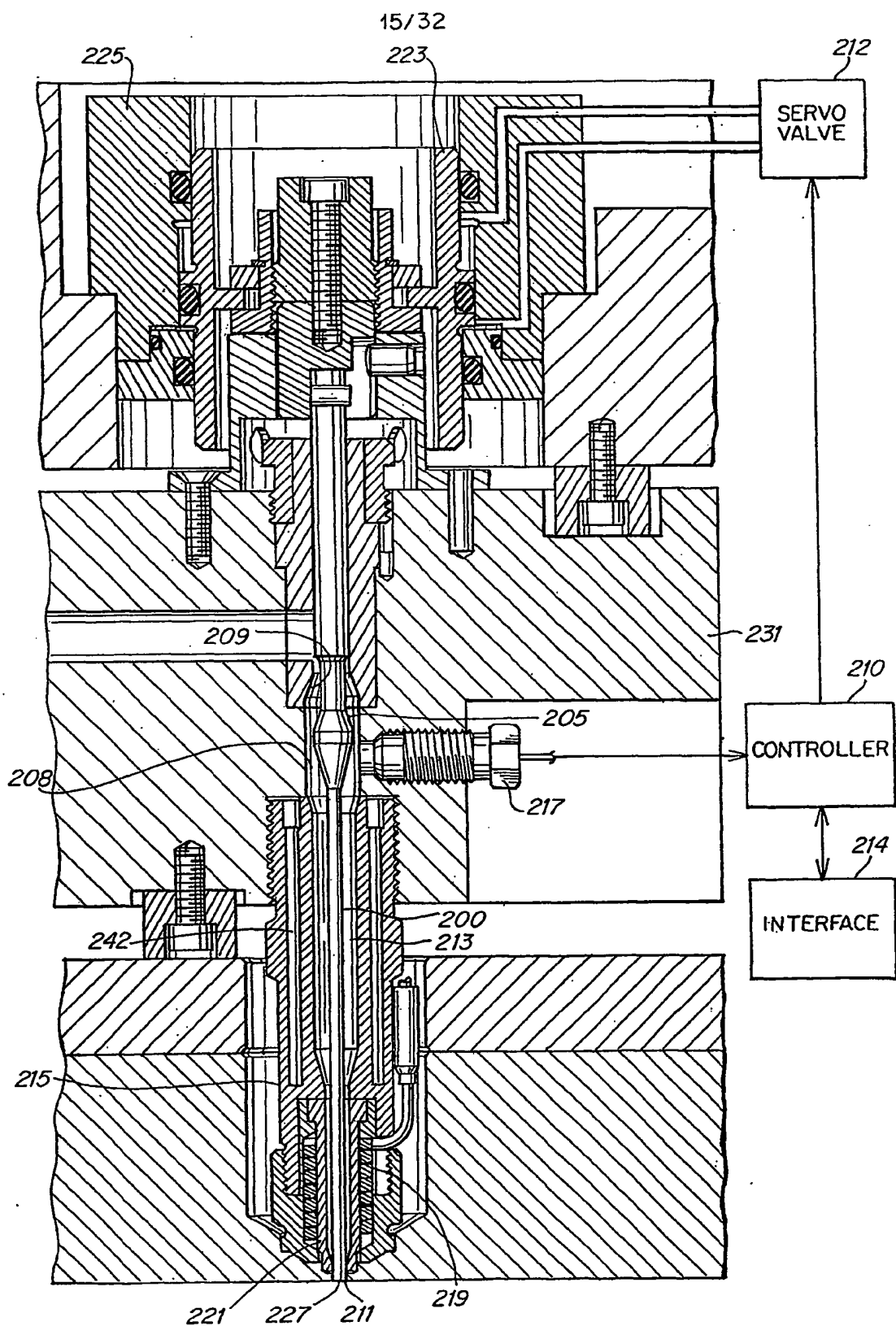


*Fig. 12*

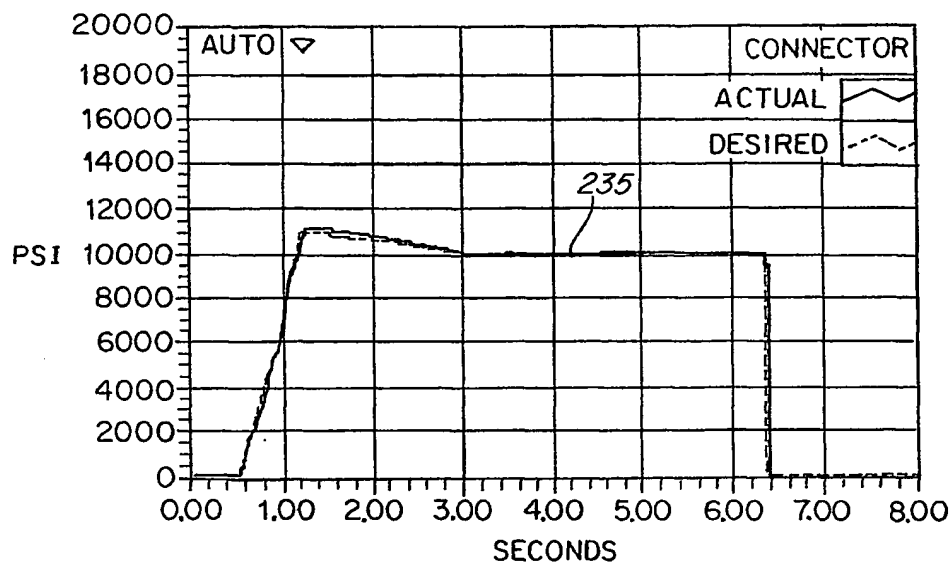
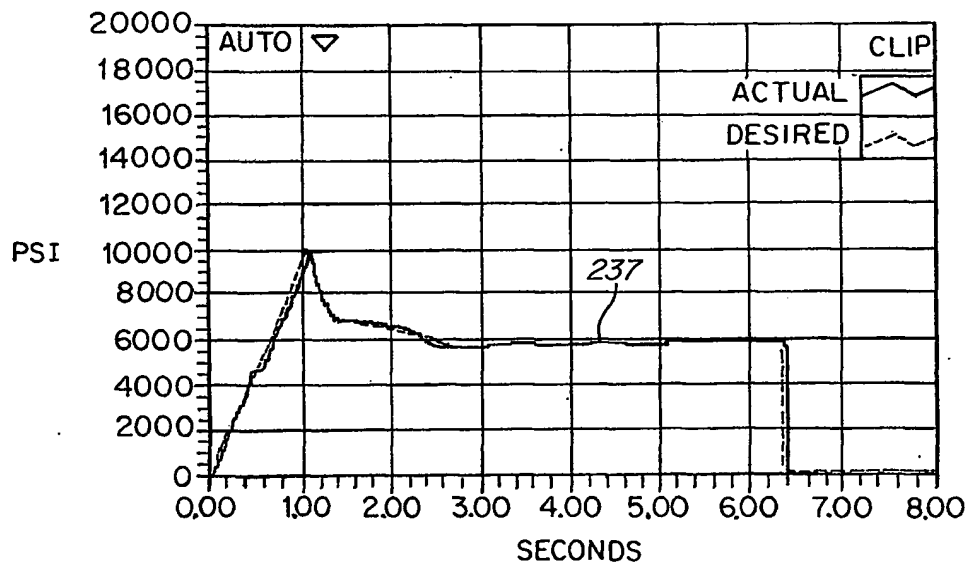




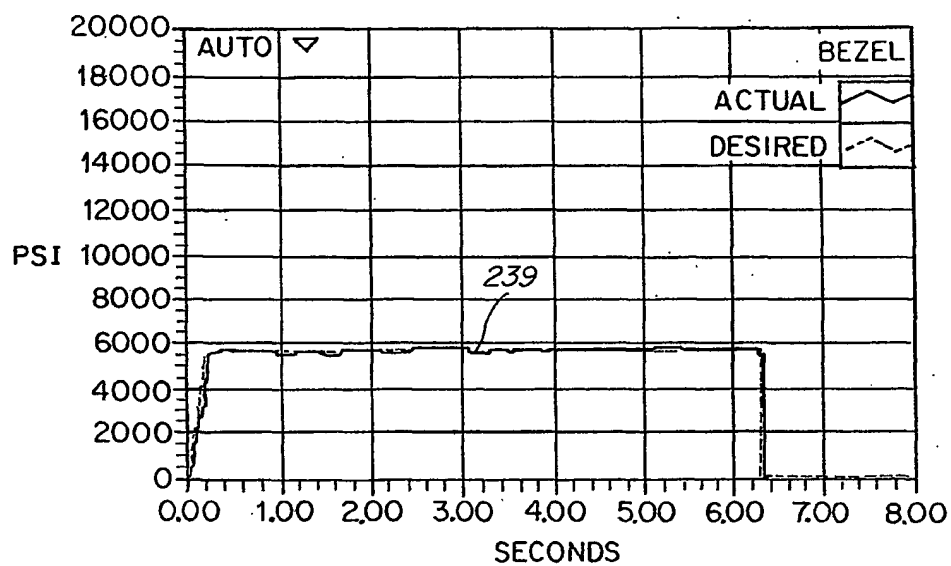
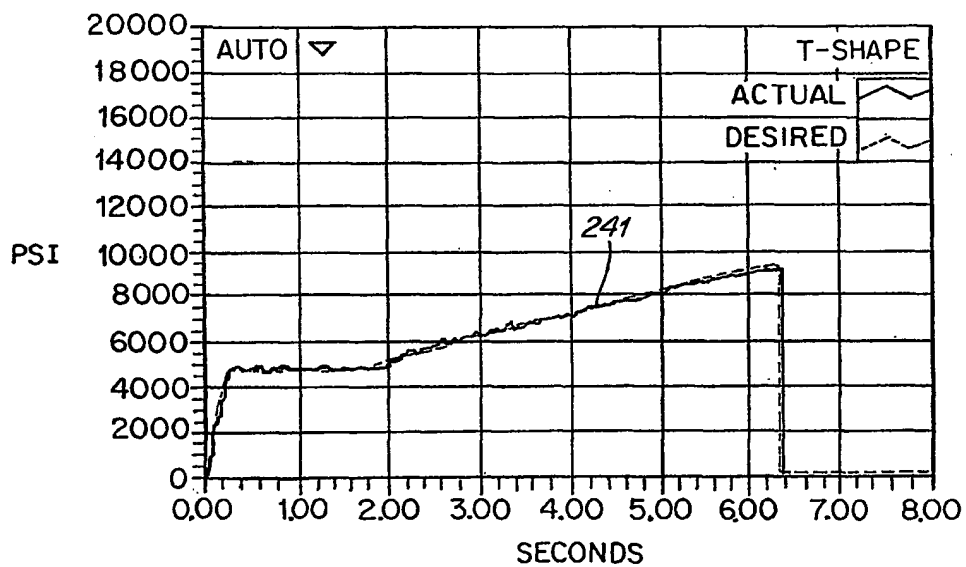


*Fig. 15*

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*Fig. 16a**Fig. 16b*

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*Fig. 16c**Fig. 16d*

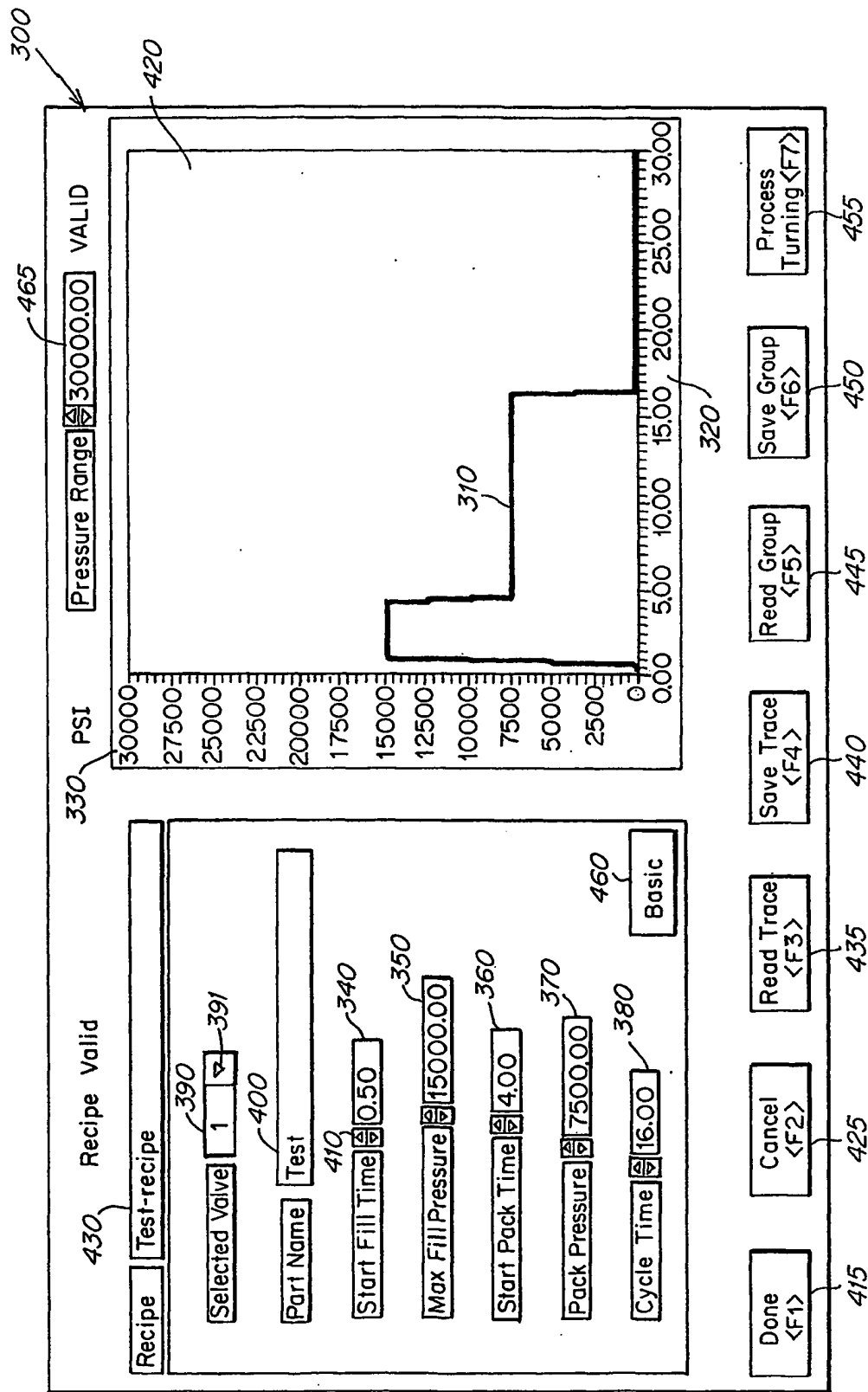


Fig. 17

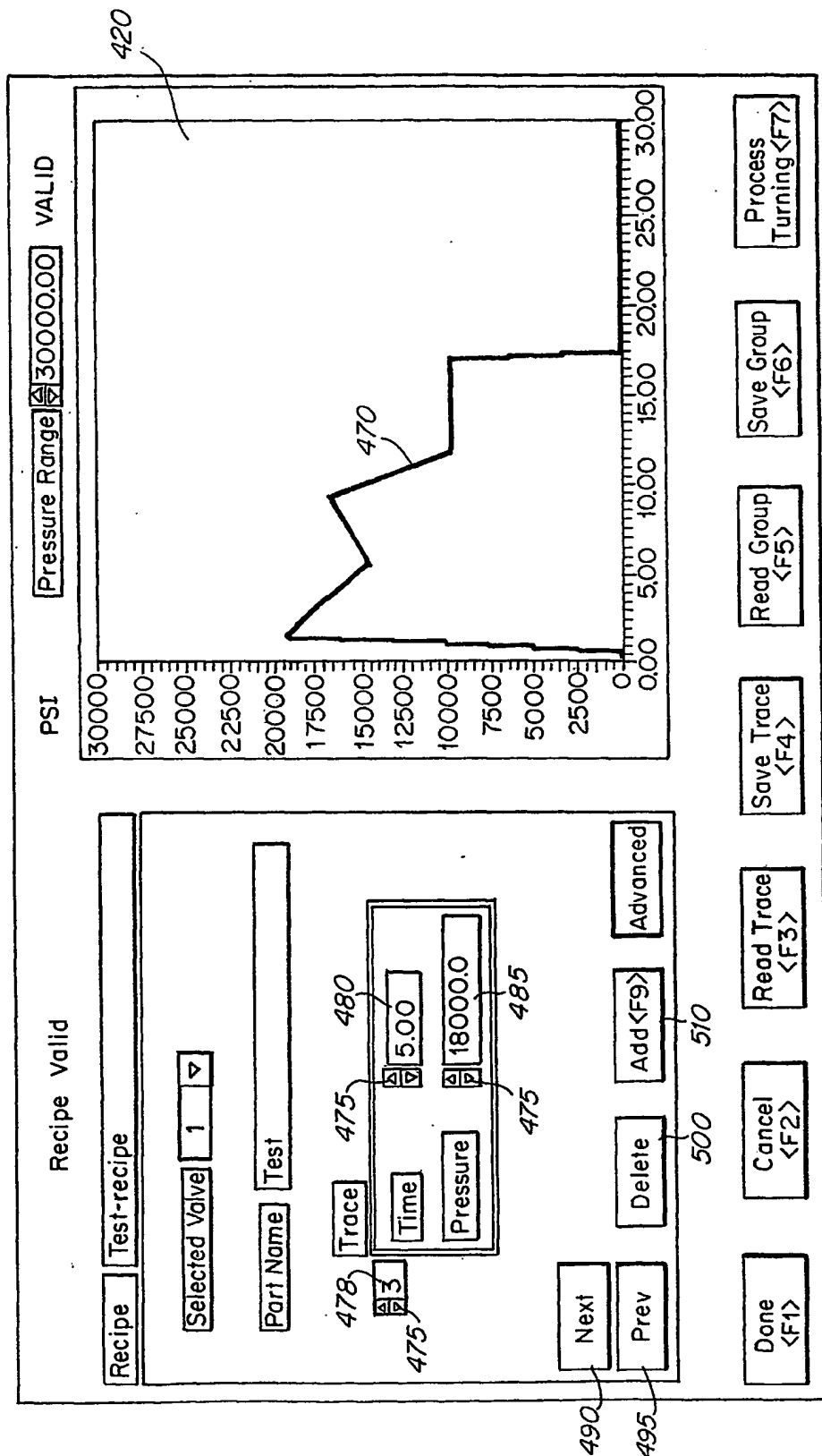
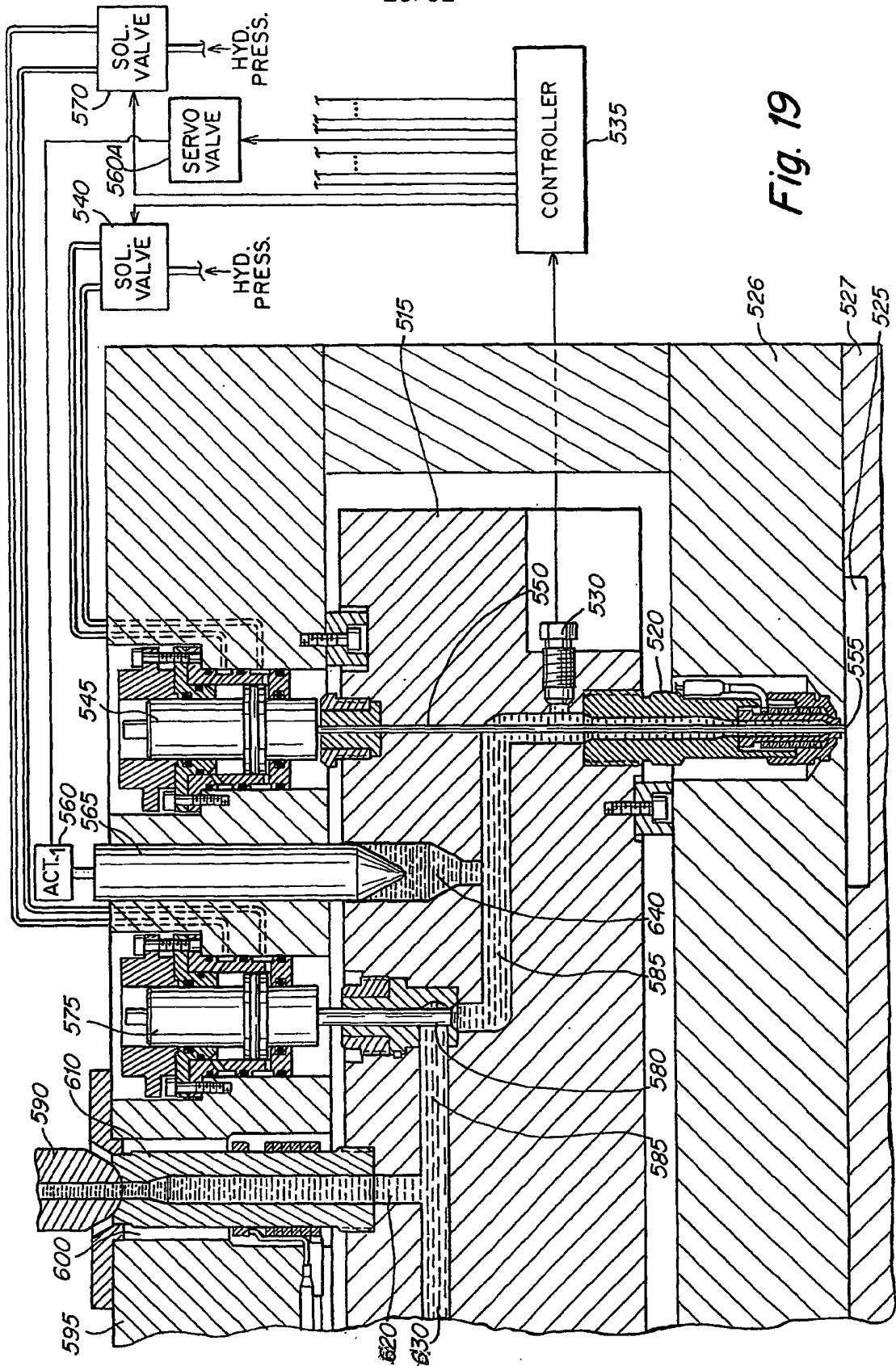


Fig. 18

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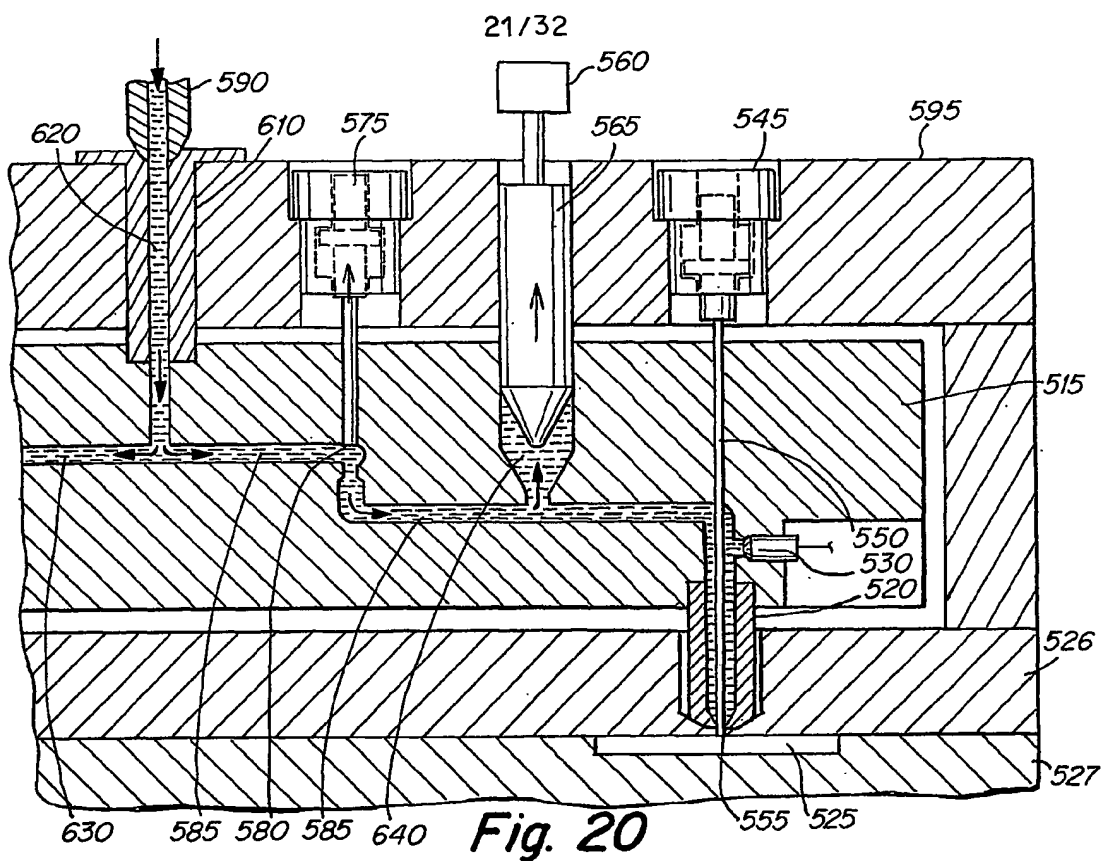


Fig. 20

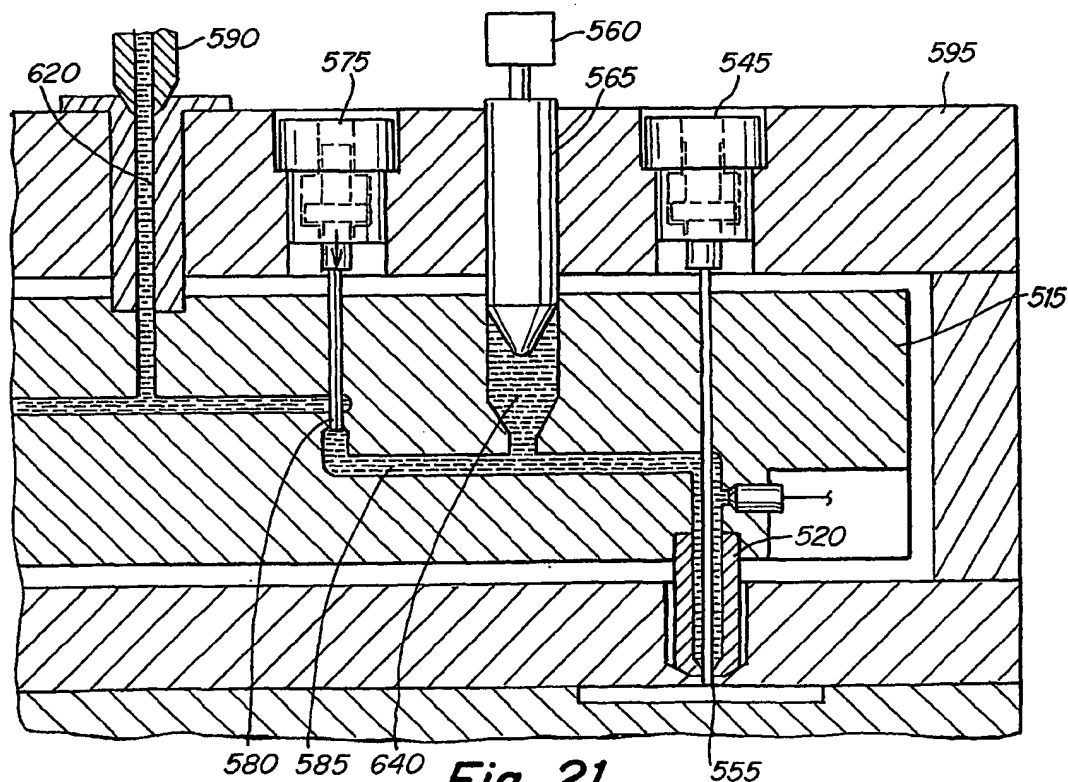
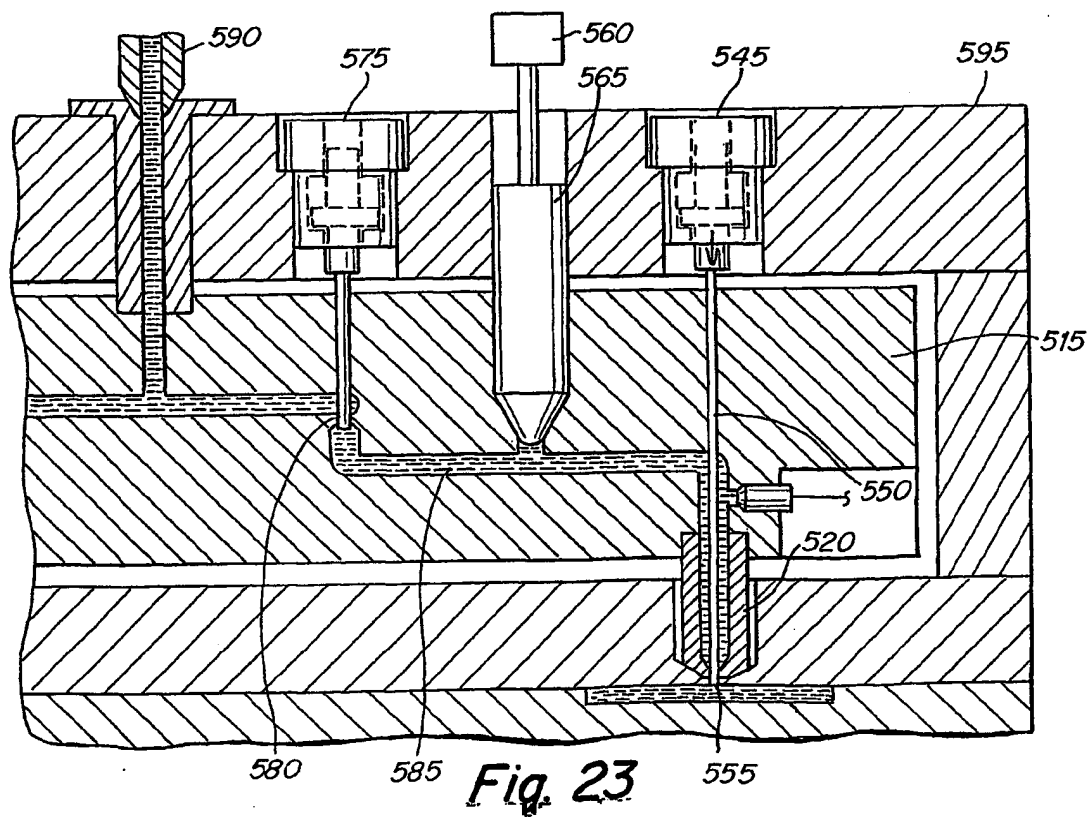
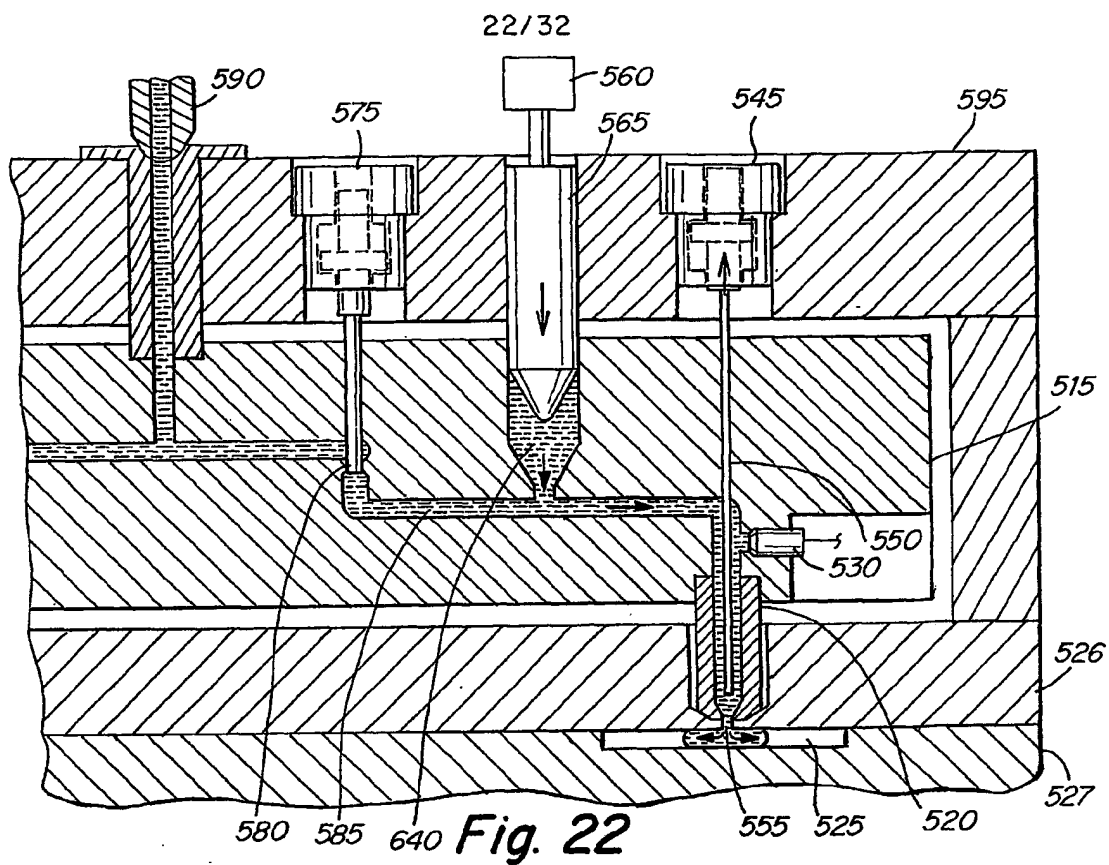
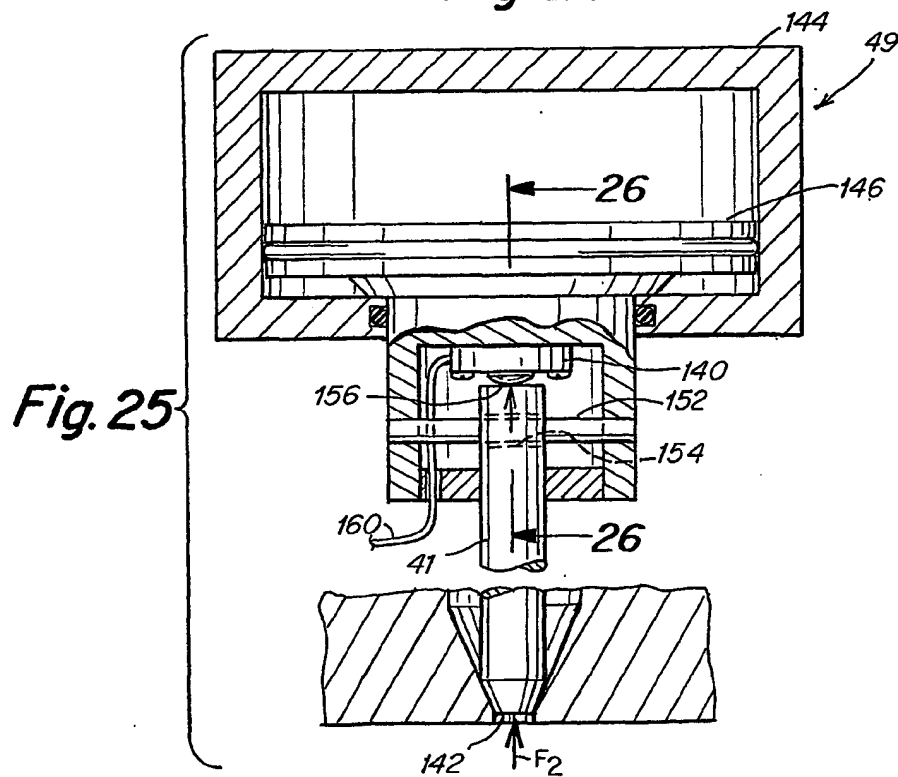
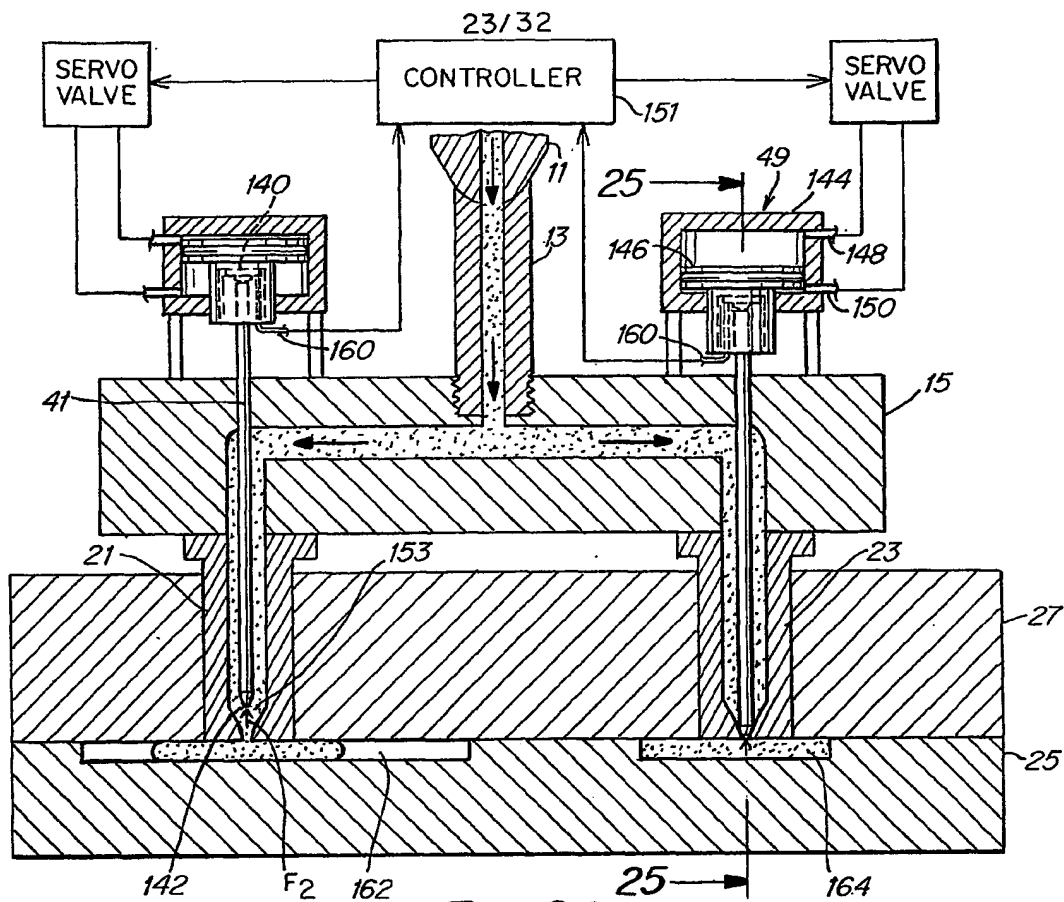


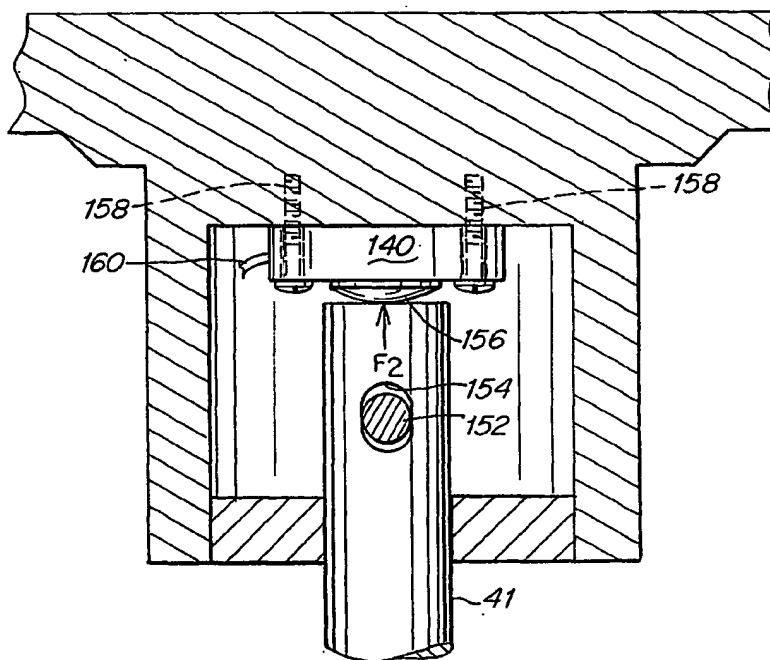
Fig. 21



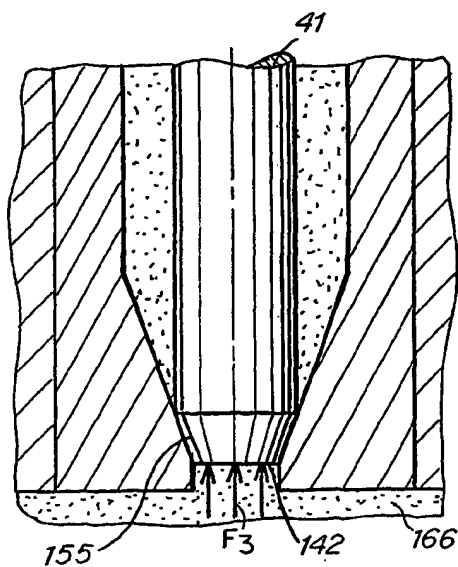




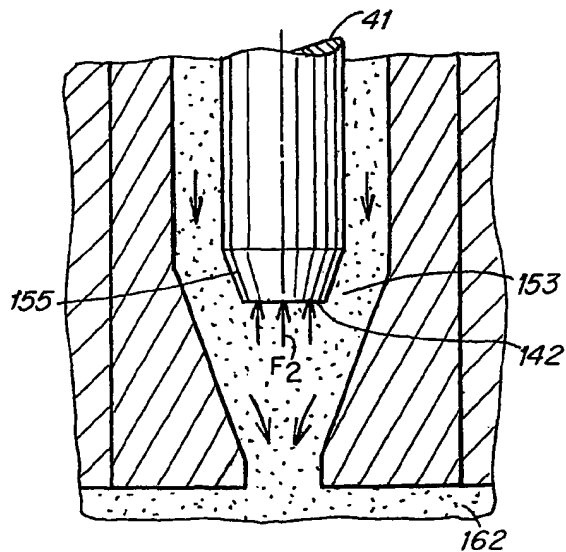
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**Fig. 26**

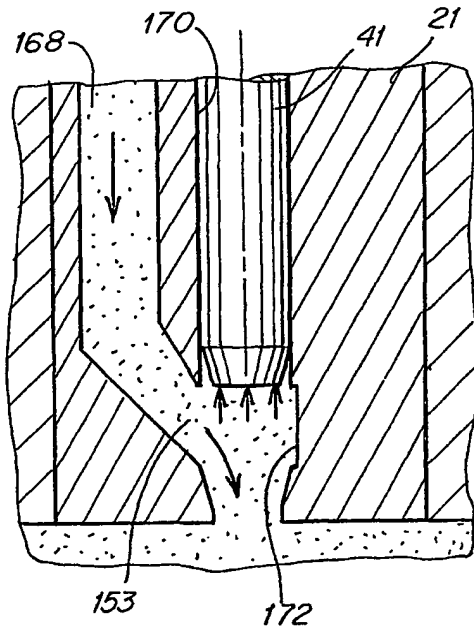


**Fig. 27A**

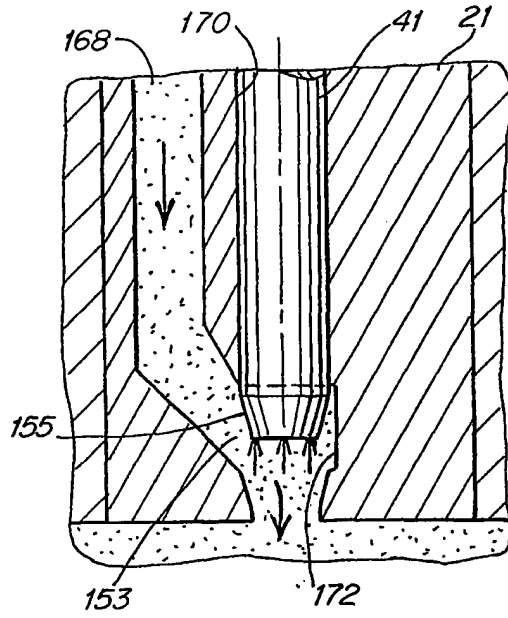


**Fig. 27B**

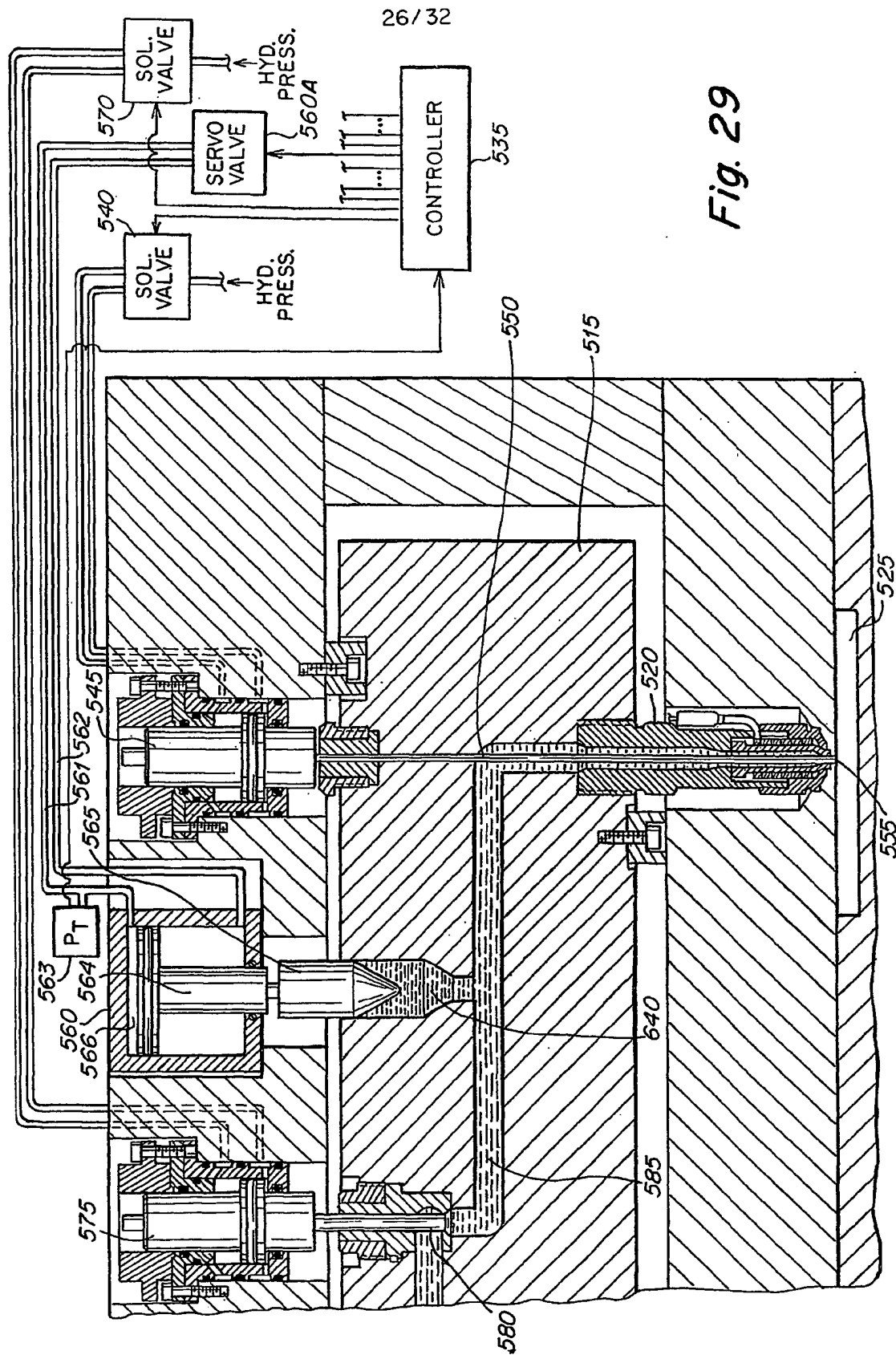
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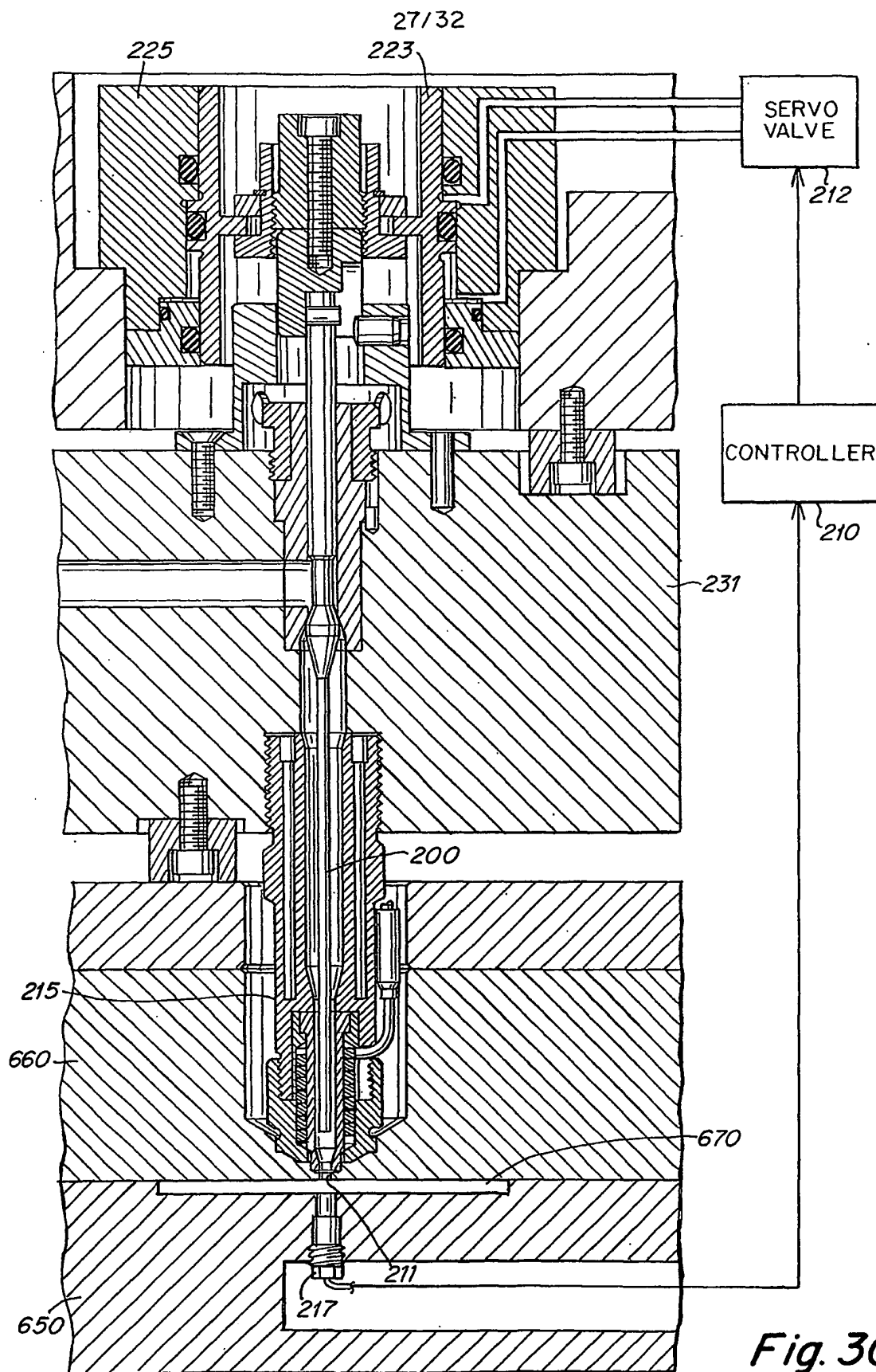


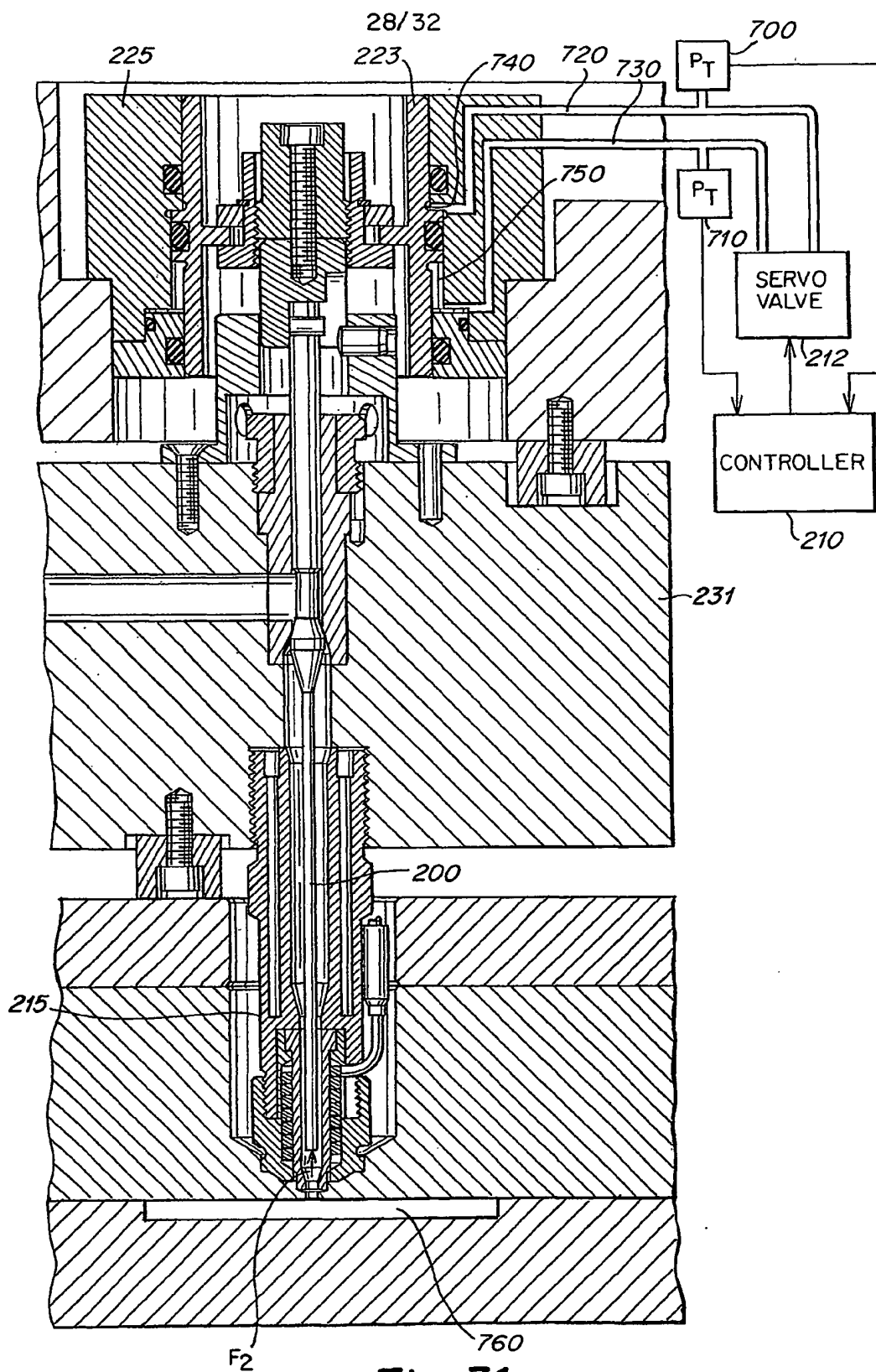
*Fig. 28A*



*Fig. 28B*







**Fig. 31**

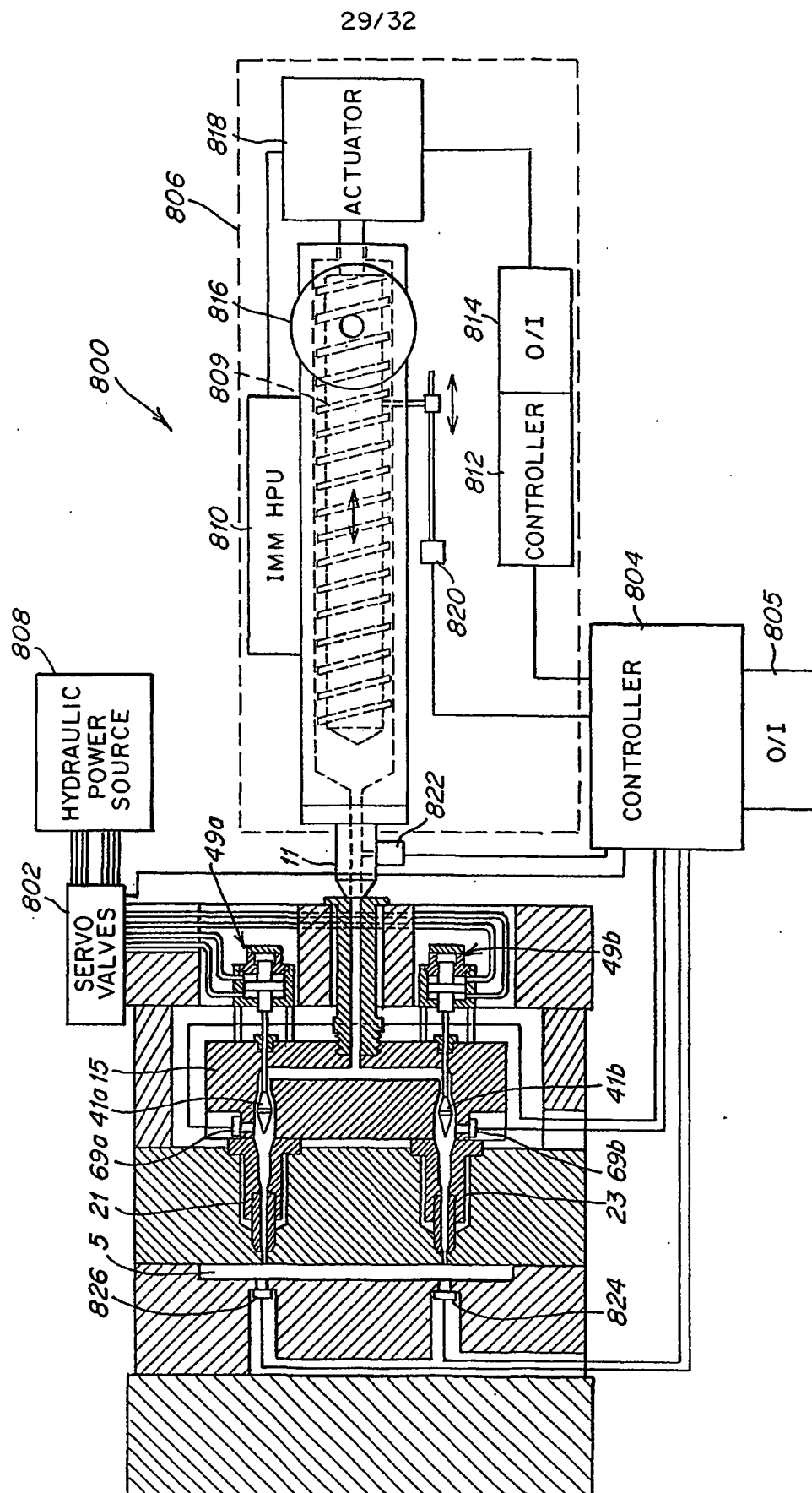


Fig. 32



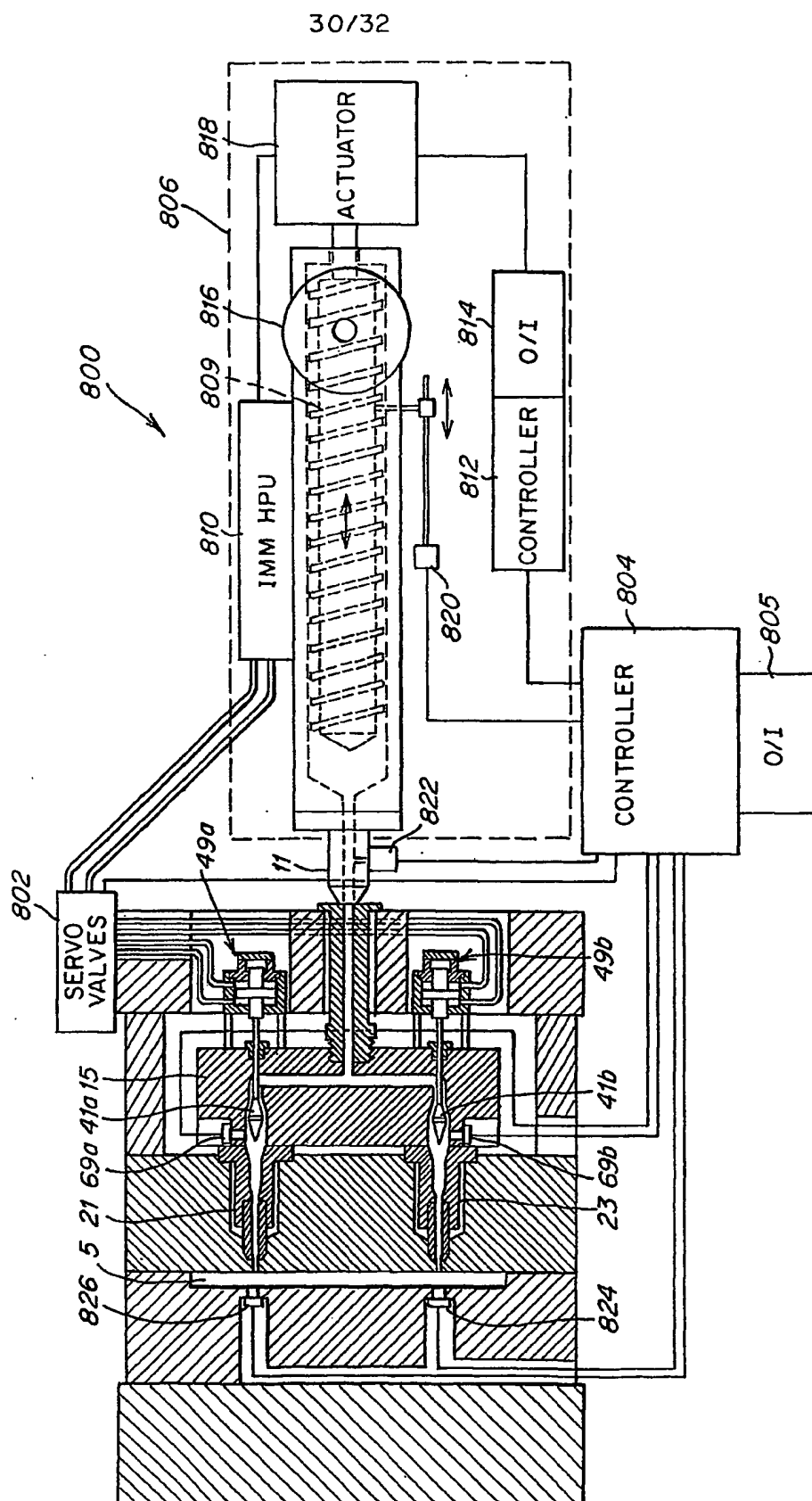


Fig. 33

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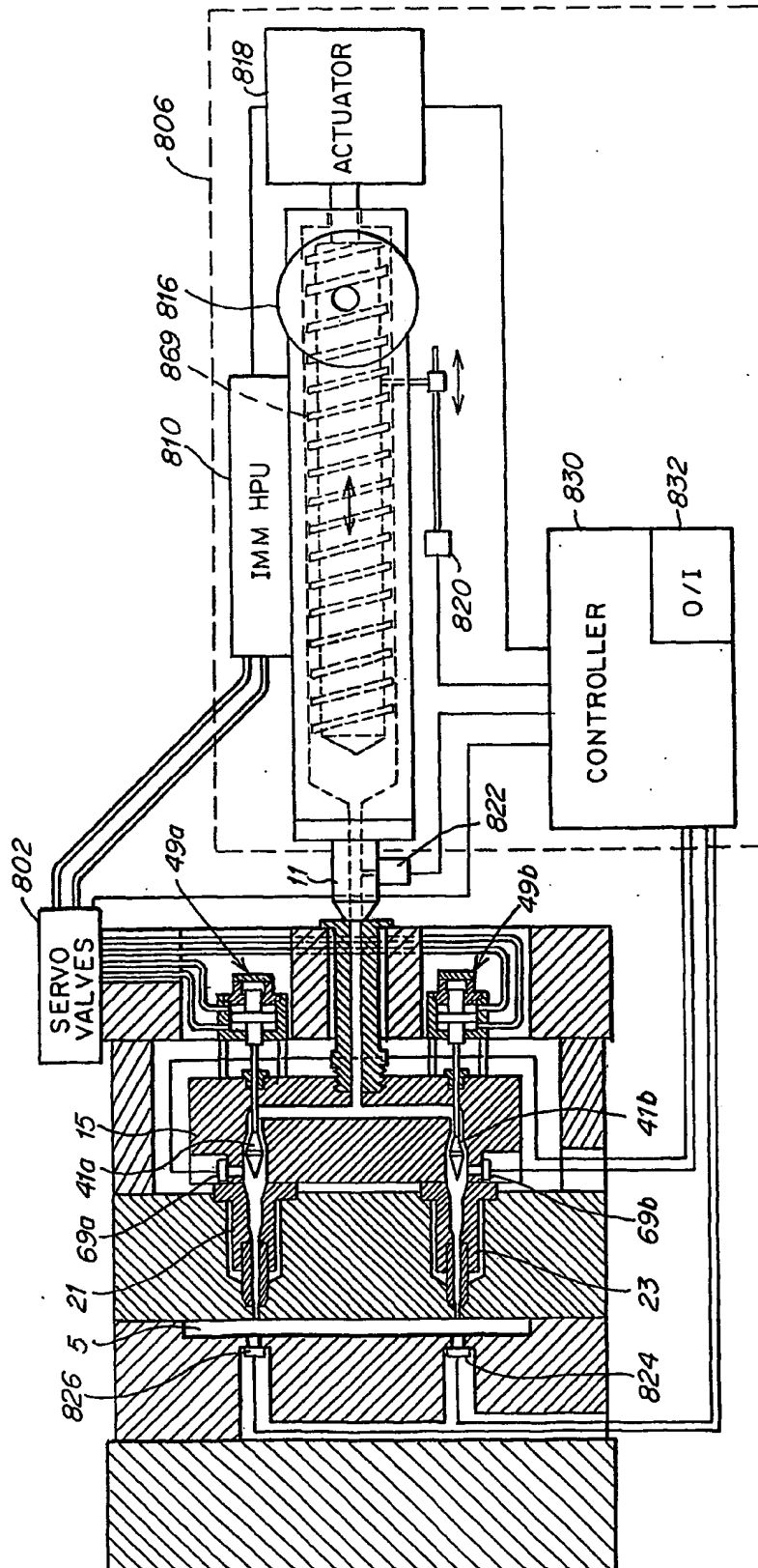


Fig. 34

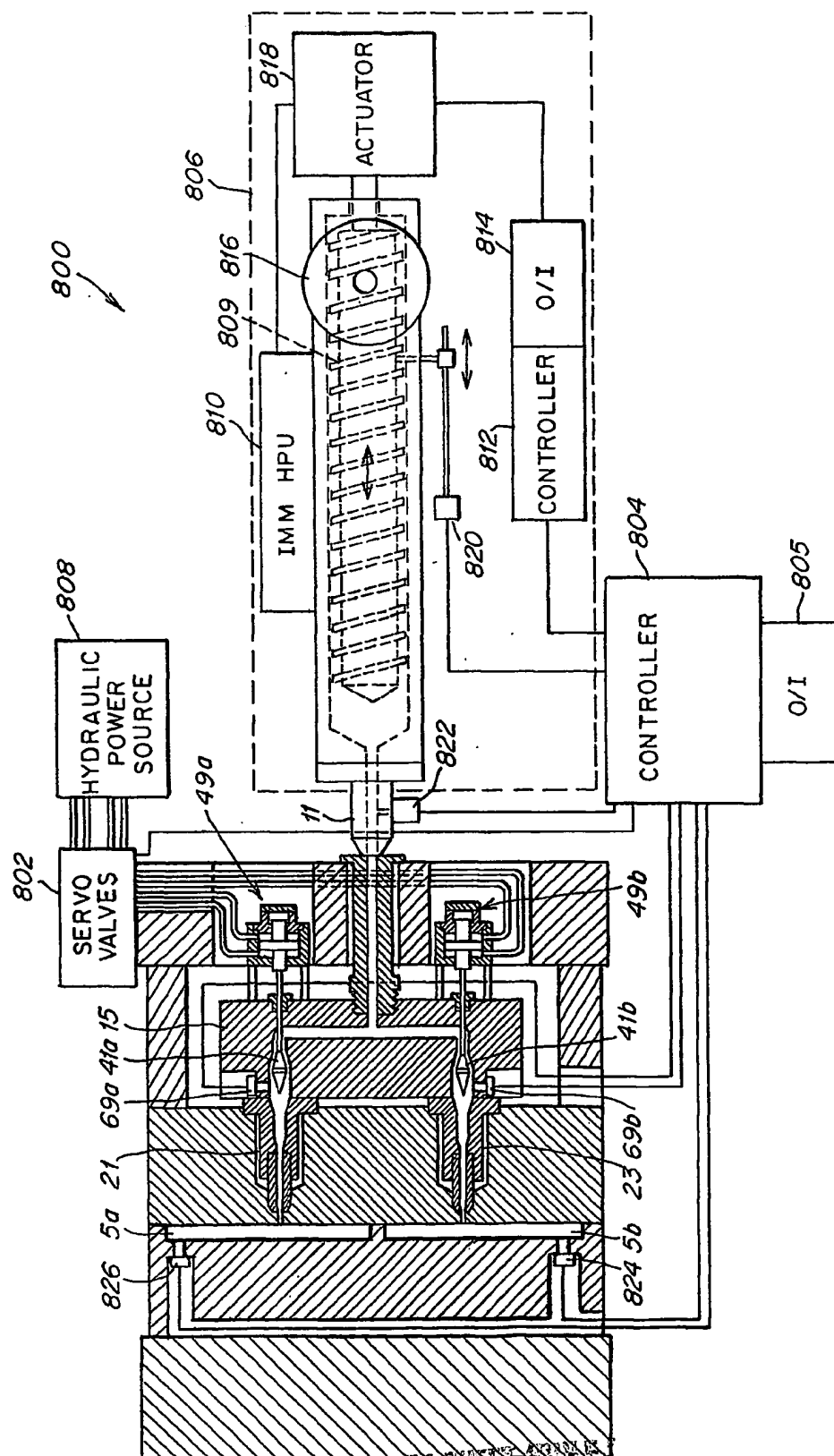


Fig. 35

## INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 01/04674

## A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 B29C45/28 B29C45/30 B29C45/77

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 B29C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

PAJ

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	US 5 556 582 A (KAZMER DAVID O) 17 September 1996 (1996-09-17) the whole document	1-3,5,8, 9 11,15, 20,28, 29,31
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## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	PATENT ABSTRACTS OF JAPAN vol. 10, no. 231 (M-506), 12 August 1986 (1986-08-12) & JP 61 063428 A (NIPPON DENSO CO LTD), 1 April 1986 (1986-04-01)	1-5
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